

# **FLOW BEHAVIOUR OF FLY ASH SLURRY**

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF

**BACHELOR OF TECHNOLOGY  
IN  
MINING ENGINEERING**

By  
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10505014



**DEPARTMENT OF MINING ENGINEERING  
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**Under the Guidance of**  
**Prof. H.K.NAIK & Prof. M.K. MISHRA**



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## **National Institute of Technology Rourkela**

### **CERTIFICATE**

This is to certify that the thesis entitled “***FLOW BEHAVIOUR OF FLY ASH SLURRY***” submitted by Sri Pradeep Oram, Roll No. 10505014 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Prof. H.K.NAIK

Prof. M.K. MISHRA

## **ACKNOWLEDGEMENT**

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## **ABSTRACT:**

The deposit of a large amount of fly ash and bottom ash discharged from coal-fired power stations is a serious problem. The amount of fly ash is larger than bottom ash. Considerable amount of recycle use is available, mainly by adding fly ash to cement. However, the addition of fly ash to cement is limited because the production rate of cement is leveled off, and also the concentration of fly ash in cement is limited.

Mine void filling is an potential area which can provide scope for environmentally safe and large volume utilization of fly ash. For this, effective transportation of the fly ash and creation of fill with acceptable strength characteristics are the two main issues to be addressed. Hydraulic conveyance is a potential technology for mine void filling. Water used in hydraulic conveyance can be recycled between the fill site and the slurry preparation unit. Current research in hydraulic conveyance is focused among other techniques on the transportation of densified slurries and paste. The purpose of such conveyance technologies is to minimize the energy consumption and water requirement per unit mass of solids transported.

On a global scale, recent studies in the area of mine void filling are primarily concerned with the utilization of mill tailings and to certain extent fly ash based, mixtures. Considerable volumes of literature exist in the use of mill tailings for underground mine fill. Investigators have studied the aspect of grain size distribution, permeability, viscosity; fill strength properties with and without additives, slurry flow characteristics, settling characteristics, slump characteristics and so on for mill tailings. Fly ash in terms of grain size and mineralogical composition is characteristically similar to mill tailings. There is, however not much literature available on direct placement of fly ash as a fill material. Investigations on the fly ash have been largely confined to determining Physico-chemical properties, strength properties (as cement substitute or with binders), leaching characteristics, and application for the improvement of soil characteristics for plant growth and so on. Studies based on hydraulic conveyance of the fly ash are not readily seen in the literature. The present study therefore makes use of literature available in terms of fly ash, to design and conduct different experiments on settling rate and hydraulic transportation aspects of fly ash.

Different experiments were conducted to find the pH at different levels of lime, cement and gypsum. These were done to further utilize the cementing property of fly ash and its use for support and fill the mine voids as well as construction of cement of different strength levels. It was observed that the strength level increase with the increase in the percentage of lime and it was observed to be maximum at 4% of lime and 8 % cement and 4% gypsum. Thus as pH is directly related to strength so it indicated that the strength characteristics was further enhanced using the aforesaid composition. The SEM of the samples were done to study the characteristics of individual elements as the element having spherical shapes showed maximum pozzolanic character. The flow characters were studied using the CFD software which showed the particles flow was in turbulent manner and there is a critical velocity below which very few materials get transported and on exceeding this also the particles stick to the walls and less transportation takes place. In order to fulfill the raw data of the software experiment for moisture content, turbidity, density, and specific gravity were done. The initial model for importing into the FLUENT was done using the GAMBIT software. Thus all the relevant data like velocity, density, friction loss, particle motion etc were graphically obtained from the software and the results was analyzed.

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# **CHAPTER 1**

**INTRODUCTION**

**BACKGROUND**

**OBJECTIVE**

**METHODOLOGY**

## **INTRODUCTION:**

Fly ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal-fired power plants, whereas bottom ash is removed from the bottom of the furnace. In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now require that it be captured prior to release. Depending upon the source and makeup of the coal being burned, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silicon dioxide ( $\text{SiO}_2$ ) (both amorphous and crystalline) and calcium oxide ( $\text{CaO}$ ).

The thermal power plant ash generation has increased from about 40 million tonnes during 1993-1994 to 120million tonnes during 2005-06 and is expected to be in the range of 175 million tonnes per year by 2012, on account of the proposal to double the power generation. Coupled with this, the deteriorating quality (increasing ash quantity) of coal is expected to aggravate the situation.

More than 120 million tonnes of coal ash are discharged from power plants in India. The utilization rate is around 40%, and the rest is disposed of on land. Seventy percent of total utilization is covered in the cement industry, in which a large increase in utilization is not expected in the future because of limits to acceptable quantity.

Many kinds of environmental problems are known to be associated with the deposited fly ash such as land degradation and degradation of air and water quality. The problem of storing the fly ash creates considerable demand for land, thereby putting pressure on the available land .The environmental problems from the stored fly ash get aggravated under certain circumstances. For example, during hot and dry seasons under wind flow conditions, particulate loading in the atmosphere increases significantly from the fly ash heaps/ponds creating health hazards. During the periods of heavy precipitation overflow from the fly ash ponds can contaminate the surrounding water bodies and agricultural lands.

On a global scale, recent studies in the area of mine void filling are primarily concerned with the utilization of mill tailings and to certain extent fly ash based, mixtures. Considerable volumes of literature exist in the use of mill tailings for underground mine fill. Investigators have studied the aspect of grain size distribution, permeability, viscosity; fill strength properties with and without additives, slurry flow characteristics, settling characteristics, slump characteristics and so on for mill tailings. Fly ash in terms of grain size and mineralogical composition is characteristically similar to mill tailings. There is, however not much literature available on direct placement of fly ash as a fill material. Investigations on the fly ash have been largely confined to determining physico-chemical properties, strength properties (as cement substitute or with binders), leaching characteristics, and application for the improvement of soil characteristics for plant growth and so on. Studies based on hydraulic conveyance of the fly ash are not readily seen in the literature. The present study therefore makes use of literature available in terms of mill tailings and also fly ash, to design and conduct different experiments on settling rate and hydraulic transportation aspects of fly ash.

### **GOAL OF THIS STUDY:**

The main aim of this study is to *transport Fly Ash to underground mine voids*. It would address the large scale disposal of fly ash with added benefit of controlling subsidence as well as other strata problem.

**SPECIFIC OBJECTIVE:** The large scale transportation of fly as envisioned encompass the following specific objectives to be fulfilled.

The specific objectives of the study are:

- To Study characteristics of fly ash.
- To evaluate the flow behavior of the fly ash samples collected.
- To simulate numerical model using FLUENT-GAMBIT software.

## **METHODOLOGY:**

To achieve the goal of the study, I have followed the following steps:

- Literature review: I have gone through different books, journals and magazines to gain knowledge about the generation, production statistics of fly ash. I have also gone through literature on the different rheological properties and factors that affect the flow behavior of fly ash slurry.
- Sample collection: I have collected samples from local power plant.
- Data analysis: I have conducted experiments using different percentage of additives to analyze the properties of the fly ash sample collected.
- I ran a computer program i.e. Fluent-Gambit software to simulate the flow behavior of fly ash slurry with different percentage of additives. Fluent is worldwide established software for computational fluid dynamics. So I used the software without any verification.
- results and discussion

The general layout of the project report involves five chapters. Chapter one gives the basic background, aim and specific objectives. Chapter two details the review of the available pertinent literatures. Chapter three describes the mechanism and materials adopted for the investigation and it is followed by the discussions on tests in chapter four. Chapter five shows the conclusion and recommendation for further study.

# **CHAPTER 2**

**LITERATURE REVIEW**

GENERATION

CLASSIFICATION

UTILIZATION

**CHARACTERISTICS OF FLYASH SLURRY**

## **LITERATURE REVIEW**

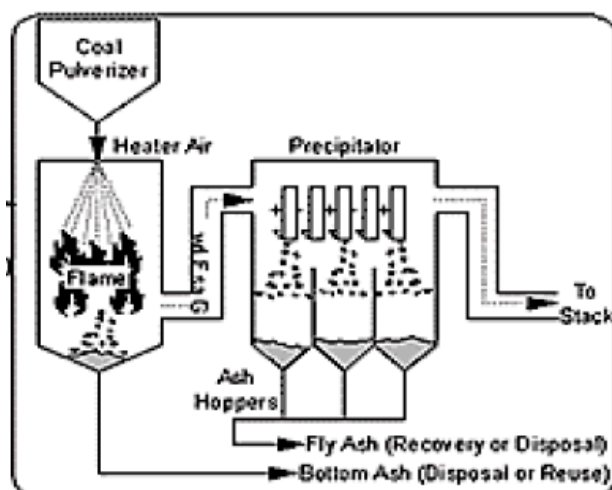
One of the potential large volume disposal techniques for the vast quantities of the fly ash generated in the country is to utilize the material as filler in the abandoned or in the active mines, whether surface or underground. Due to the convenience of accessing the difficult disposal sites, and also due to continuity of the operations, hydraulic conveyance of the fly ash stands apart as viable and potentially economic technology. Availability of the fly ash in the proximity of a mining site can create favorable conditions for its use as a fill medium.

## **GENERATION OF FLY ASH:**

The fly ash produced from the burning of pulverized coal in a coal-fired boiler is a fine grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, bag houses, or mechanical collection devices such as cyclones.

In general, there are three types of coal-fired boiler furnaces used in the electric utility industry. They are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. The most common type of coal burning furnace is the dry-bottom furnace.

When pulverized coal is combusted in a dry-ash, dry-bottom boiler, about 80 percent of all the ash leaves the furnace as fly ash, entrained in the flue gas. When pulverized coal is combusted in a wet-bottom (or slag-tap) furnace, as much as 50 percent of the ash is retained in the furnace, with the other 50 percent being entrained in the flue gas. In a cyclone furnace, where crushed coal is used as a fuel, 70 to 80 percent of the ash is retained as boiler slag and only 20 to 30 percent leaves the furnace as dry ash in the flue gas. A general flow diagram of fly ash production in a dry-bottom coal-fired utility boiler operation is presented in Figure.



**Figure 2.1 Generation of ash at the power plants**

In India coal/lignite based thermal power stations account for more than 55% of the electricity installed capacity and 65% of electricity generation. The ash content of the coal used at the thermal stations ranges from 30-40%, with the average ash content around 35%. Since low ash, high grade coal is reserved for metallurgical industries, the thermal power plants have to utilize high ash, low grade coal.

## **COMPOSITION:**

<b>Component</b>	<b>Bituminous</b>	<b>Sub-bituminous</b>	<b>Lignite</b>
SiO <sub>2</sub>	20-60	<u><b>40-60</b></u>	<u><b>15-45</b></u>
Al <sub>2</sub> O <sub>3</sub>	5-35	20-30	10-25
Fe <sub>2</sub> O <sub>3</sub>	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO <sub>3</sub>	0-4	0-2	0-10
Na <sub>2</sub> O	0-4	0-2	0-2
K <sub>2</sub> O	0-3	0-4	0-4
LOI	0-16	0-3	0-5

**Table 2.1 Chemical Composition of Indian Fly Ash**



## **CLASSIFICATION:**

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5  $\mu\text{m}$  to 100  $\mu\text{m}$ . They consist mostly of silicon dioxide ( $\text{SiO}_2$ ), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminium oxide ( $\text{Al}_2\text{O}_3$ ) and iron oxide ( $\text{Fe}_2\text{O}_3$ ). Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides.

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).

### **Class F fly ash:**

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime ( $\text{CaO}$ ). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer.

### **Class C fly ash:**

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime ( $\text{CaO}$ ). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate ( $\text{SO}_4$ ) contents are generally higher in Class C fly ashes.

## **UTILIZATION OF FLY ASH:**

The use of fly ash as an engineering material primarily stems from its pozzolanic nature, spherical shape, and relative uniformity. Fly ash recycling, in descending frequency, includes usage in:

- Portland cement and grout
- Embankments and structural fill
- Waste stabilization and solidification
- Raw feed for cement clinkers
- Mine reclamation
- Stabilization of soft soils
- Road sub base
- Aggregate
- Flow able fill
- Mineral filler in asphaltic concrete
- Other applications include cellular concrete, geopolymer, roofing tiles, paints, metal castings, and filler in wood and plastic products

## **CHALLENGES IN HANDLING FLY ASH:**

Various challenges have been reported in the handling and utilization of fly ash. Some of these difficulties include:

- The wet system of fly ash collection/disposal is the most common practice in India. Fly ash is mixed with bottom ash in slurry form before transporting it to ash ponds/lagoons. This process of fly ash dumping is largely unsuitable for all purposes where pozzolanic properties are essential to its use. Fineness and lime reactivity are seriously imparted and the ash from the ponds is unsuitable for use in most applications needing strength.
- Variations in ash composition are unavoidable and it largely depends on the quality of coal utilized. Customer therefore can never therefore be sure of the quality of ash available from a particular source.

- There is no system of testing, labeling and packing of coal ash. Most of the ash producers are not equipped to certify the quality or specifications of an ash. This undermines the confidence of the end users of the fly ash from a particular source compelling them to set up such testing and other facilities at their own cost. This obviously makes them somewhat reluctant to use it.
- Most thermal stations are located in remote areas and the user industry faces difficulty in lifting and transporting the fly ash.

## **CHARACTERISTICS OF FLY ASH SLURRY:**

### **Settling properties**

Tests on settling rates establish the ease with which solid-liquid separation takes place in slurries during filling activity, and the tests also provide a means of determining the recycled water quality. Settling characteristics of fly ash –water slurries which have bearing on the aspects indicated above are not available in reported literature.

### **Process of transportation of fly ash:**

Significant attention has been paid in recent decades for the hydraulic transportation of solids in the pipelines due to several considerations. The advantages of the technique include reduced airborne dust, material handling on continuous basis, easily automation process etc and so on. The availability of water in mining areas and the technical simplicity of the process, have lead to the more or less standard practice of hydraulic transportation of sand or such similar media for filling of voids in under ground mines.

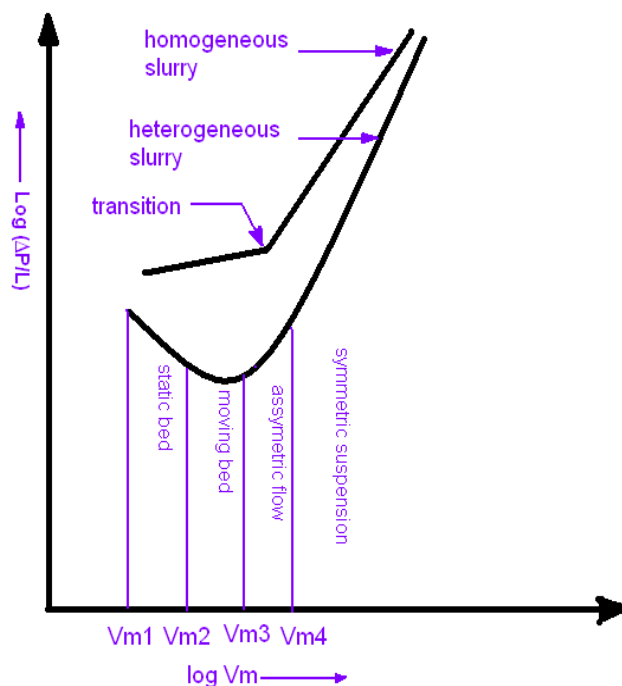
## **SLURRY FLOW BEHAVIOR:**

When a solid –liquid mixture is conveyed through a pipe, different conditions of flow may be encountered depending on the properties of the solids, conveyed liquid, and the characteristics of the pipeline. The different hydraulic flow conditions of slurry are homogeneous, intermediate and saltation flow. As the name suggests, the flow is homogeneous if the various properties of the suspensions (like solid concentration, density, viscosity) do not change across the pipe. Homogeneous flow of suspension is possible if the following conditions are satisfied:

- The solid particles are very finely dispersed and light.
- The slurry flow rate is sufficiently high.
- The solid concentration is high.

For homogeneous flow it is essential to have the terminal settling velocity of the particles as small as possible so that the concentration gradients do not exist.

Homogeneous suspensions behave like single component fluids and their flow can be described using a suitable rheological model. This homogeneous flow can occur either in laminar mode or in turbulent mode. The transition from laminar to turbulent mode is indicated by the change in the slope of the pressure drop -flow rate relationship.



**Figure 2.2 Flow regimes in slurry transportation**

In actual practice, no particulate suspension of practical interest behaves like a homogeneous mixture at all flow velocities. If the mean flow velocity  $V_m$  is high enough then all the particles are fully suspended and systematically distributed across section of the pipe. This is called the "symmetric suspension regime". At these velocities, the turbulent and the other lifting forces are sufficient to keep all the particles under suspension and prevent them from sliding over the pipe wall. As slurry velocity (and hence the intensity of turbulence and lift forces) is decreased, the settling tendency of the particles causes a distortion of the concentration profile and flow will

become asymmetric. The concentration of solid particles will be more at the bottom of the pipe. This results in the skewness of the velocity profile with mixture velocities being higher at the top half of the pipeline as compared to the bottom half of the pipeline. This skewness in both the concentration profile as well as in velocity profile will increase with decrease in mixture velocity. Thus the flow will become more and more heterogeneous.

At the velocities below  $VM_2$  particles tend to accumulate at the bottom of the pipe, first in the form of dunes and then as a continuous 'moving bed'. The dunes or the bed move at a considerably lower velocity as compared to that of liquid or solid particles above it. The particles at the top of the dunes or bed are made to roll and tumble by the shear stresses caused by the flow above. It is obvious that the concentration of the particles in the flow above moving bed will be much lower as compared to the average concentration of solids. The mixture velocities in these upper regions are high enough to keep the particles in suspension (Seshadri 1997).

As the slurry velocity is further reduced ( $VM < VM_3$ ) the lowermost particles of the bed become stationary and the bed thickens. The bed motion occurs essentially by the uppermost particles tumbling over one another (saltation). This region of flow is called 'stationary bed' and flow will be somewhat unstable. Below a mixture velocity of  $VM_4$  the bed up and high pressure gradient will be required to maintain flow. In fact as soon as the bed starts forming below a velocity,  $VM_2$  the pressure gradient would show a reversal and the pressure increases with decreasing mixture velocity resulting in the choking of the pipeline (Seshadri 1997). Above mentioned flow behavior would be strictly valid as long as the particles are equal in size. However in applications such as stowing and filling the particle size in the solids transported varies over a wide range. Hence, at any given mixture velocity the smallest particles may be homogeneously distributed across the pipe cross-section, whereas, concentration gradients would be prominent for the larger particles. Also the largest sized particles would tend to settle first while the other fractions are still under suspension. Thus, for given mixture if all the particles are in suspension then the concentration profile would be uniform for smallest size fraction, whereas it tends to become increasingly non-uniform as the size of the particles increases. This would make the Suspension flow near the bottom of the pipe increasingly coarser as compared to that flow at the top of the pipe. As the mixture velocity is reduced all the particles belonging to larger size fractions would be traveling in the bottom half the pipe and they tend to settle first. Thus, for

multisided particulate suspensions there will be a combination of homogenous and heterogeneous flow. Further, the transition velocities (VM1 to VM4) are not clearly defined and the different flow regions are not clearly distinguishable (Seshadri. 1997).

Within the transition zone between heterogeneous and saltation regimes, there is a unique velocity corresponding to minimum head loss in the pipeline, below which the settling of solids will occur, but above which, the flow is homogeneous. This velocity is termed the critical velocity. VC (Kokpmar and Gogus. 2001). For a given concentration of solids critical velocity for the slurry flow refers to conditions of least frictional pressure losses. The conveyance of the slurry at this velocity regime results in decreased power requirements on the transportation system and at the same time ensures reduced pipe damage due to wear. Further, the addition of polymeric medium such as the Polycrylamide and its various graft components, in small quantities, is noted to have an effect on pressure reduction in slurry transportation.

It is almost impossible to derive general correlations for the estimation of various transitions velocities in slurries of different materials. This is because it is not feasible to take into account the effect of so many parameters which, differ from the slurry to another. The presence of fine particles would increase the viscosity of the slurry resulting in increased resistance to settling behavior of large particles. Thus, the particles in the slurry might be fully suspended even at moderate mixture velocities, whereas in the absence of fine particles the larger particles would have settled down.

Although several attempts have been made to incorporate the effect of different parameters into the correlations, the studies have been only partially documented in literature with each study having its own limitations and range of applications (Levy, 1999; McCabe. 1993; Seshadri, 1997; Kokpmar, 2001)

Essentially the prediction of critical flow velocity in pipelines carrying solidliquid mixtures with a sufficient accuracy is of considerable importance to researchers and practicing engineers. On account of the minimum cost of slurry transportation at this velocity, the work done by Kokpmar and Gogus (2001), refers extensively to the various empirical expressions that have been generated by earlier researchers for critical velocity. The terminal settling velocity of the solid particles is taken into consideration in the proposed model of Kokpmar and Gogus (2001), for

the determination of critical velocity of slurry flow. The approach differs from the earlier formulations on account of the consideration of the settling velocity of particles. The Kokpmar and Gogus (2001), model is given by:

$$\frac{V}{gD} = 0.055 \left(\frac{d}{D}\right)^{-0.6} C_v^{0.27} (S-1)^{0.07} \left[\frac{\rho_f W_m d_s}{\mu_f}\right]^{0.30}$$

where

V = mean critical flow velocity of solid—liquid mixture (m/s);

C = concentration of solid materials by volume;

D = pipe diameter (m);

Ds = mean particle diameter (m);

S = specific gravity,

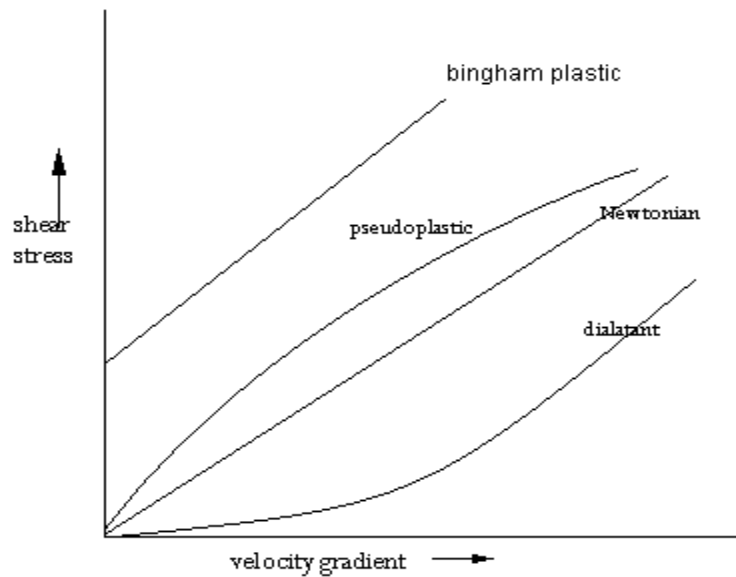
Wm = particle settling velocity in mixture flow (m/s);

uf= dynamic viscosity of fluid (kg/m-s);

pf. =density of fluid (kg/m<sup>3</sup>); and

g= gravitational acceleration (m/s<sup>2</sup>).

Depending upon the relationship (rheogram) between shear stress and rate of shear strain, fluids are classified into different categories as shown in Figure 2.2 (McCabe et al. 1993). The relationship between these two parameters is linear when the fluids are Newtonian. With respect to this behaviour an upwardly concave curve represents pseudo plastic behaviour, whereas. a downwardly concave curve represents dilatants behaviour. The fluids which do not exhibit any flow until threshold shear stress ( $\tau_0$ ). represent Bingham, behaviour (McCabe et al, 1993).



**Figure 2.3 shear stress vs rate of shear strain**

In the Georgia Iron Works (GIW) pipeline design manual Addie (1982) indicated that the flow of a solid—liquid mixture through a pipe is a complex phenomenon with the flow characteristics and subsequent pipe friction being dependent upon size distribution, shape, density, and concentration of the solids, pipe diameter, mean velocity, slope of the pipeline and so on. Addie (1982) categorized slurries into settling and nonsettling types depending on the settling velocity of the solid particulates in the slurry. Slurries containing particles with settling velocities higher than 1.5 mm/s are termed as settling slurries, whereas, the slurries with particles having settling velocities below 1.5 mm/s are termed as nonsettling slurries.

Nonsettling slurries flowing in a pipe have a uniform distribution of particles across the flow section and exhibit axis-symmetric velocity distribution. Procedures to estimate friction pressure gradients for the nonsettling slurries under laminar and turbulent flow conditions are presented in this paper. The procedures require tube type viscometer measurements and estimation of pseudofluid (slurry) densities.

It may be generally stated that, no reliable method exists for the estimation of the flow properties of nonsettling slurries based on calculations from the properties of the solids and carrier liquid. In practice, slurry transport of nonsettling slurries in laminar flow regime is avoided primarily because larger particles may settle to the bottom of the pipe forming a stationary bed. In most



cases, systems are designed to run at velocities slightly in excess of those of the transition point (Addle, 1982).

Settling slurry in a pipe normally flows as a heterogeneous mixture in which a portion of the solid particles are carried as suspended load and the remainders are carried as bed load. The bed load or stratification ratio (R), which is the ratio of the bed load transport to total transport, is a useful parameter to characterize the flow conditions. Since the mechanism of suspension and turbulence, is a function of mean velocity in the pipe, the value of R is also a function of  $V_m$ . At a sufficiently high mixture velocity, all of the solid particles will be conveyed as suspended load or as a pseudo homogeneous suspension for which  $R=0$ . At slower velocities the solid particles tends to settle towards the bottom of the pipe with the result that some of the transport is bed load transport and little additional resistance resulting from suspended—load transport; therefore, the friction pressure gradient diverges more and more from the water curve as R increases due to reducing  $V_m$ . The lower limit of the heterogeneous suspension occurs when the velocity is reduced to the deposit velocity and the solids start to form a stationary bed. A small stationary bed is harmless, but there is no reason to waste a part of the flow cross section with a stationary bed. In order to preclude a stationary bed, Pipelines are designed so that  $V_m > \text{deposit velocity}$ . For settling slurries with centrifugal pumps as prime movers, the conveying velocity is normally well above the deposit velocity in order to operating velocity. The velocity  $U_u$ , at the threshold of turbulent suspension is (Addle. 1982)

$$U_u = 0.6V_t \sqrt{\frac{8}{f_t}} 45(d/D)$$

$V_t$  = terminal Settling velocity,

$f_t$  = friction factor of fluid flowing at velocity  $V_m$ ,

$d$  = particle diameter,

$D$  = internal pipe diameter.

Specific Energy Consumption (SEC) is the energy required to move one kg of solids in a horizontal distance of one meter. The most efficient slurry transport is achieved when the SEC is minimum (Addle, 1982).

$$SEC = I_m / S_s * C_{vd}$$

Where:

$I_m$  = friction pressure gradient in ft of water per ft of pipe,

$S_s$  = specific gravity of the solids and

$C$  = delivered volume concentration.

Panda and Singh (2000), described the viscous effects of transportation of fly ash slurries at 30-70% solids concentration by weight using Hakke rotational viscometer (RV 100). The study showed that the slurry represented Newtonian behavior up to 50% concentration by weight of solids in the slurry. Beyond this concentration slurry exhibited pseudo plastic behavior. When the mixture of fly ash and bottom ash was examined the viscosity was reported to be minimum at fly ash-bottom ash ratio of 3:2. The study also suggested that slurry transportation was possible at a higher concentration, i.e., up to 70% by weight by adding small amount (1.2%) of additive 'SHMP'.

### **Paste flow behavior:**

The term paste is used to refer to slurries which can be pumped and have consistency of a measurable slump. Paste is a densified uniform material of such mineralogical and size make up, that will bleed only minor quantities of water when at rest, experience minimum segregation, and can be moved in a pipeline at line velocities well below that of critical velocities for similar sized materials at lower slurry densities. Paste can remain setting in a pipeline for extended periods of time when no cementing materials present, without affecting the resumption of transportation operations. Paste fill operations are presently becoming more common and can offer several advantages over traditional methods for backfilling and surface disposal. Each application requires careful evaluation to find the suitability to local conditions since the paste recipe, plant design and distribution system are very much dependent on the paste characteristics and mine requirements. Literature available on paste flow behavior is essentially limited to that of applications of mill tailings refuse, mine waste and cement aggregate fills. At the same time not much reported information exists on the use of fly ash in paste flow applications.

Cooke (2001), outlined typical pipeline pressure gradients that might be encountered during the transportation of paste mixtures for two different solids concentration A methodology to determine the pipeline pressure gradients under laminar paste flow conditions using the pipe wall

shear stress was outlined in this paper. Cooke also indicated that no exact solution for the turbulent flow of paste was possible and that only a rough estimate could be made based on pseudo fluid approximation for the paste.

Paste systems in general are reported to operate in laminar flow. The paste flow design system should consider minimum pressure gradient as a design factor to prevent the settling of paste unlike the minimum operating velocity which is a design requirement for slurry transportation (Cooke, 2001). Loop tests are recommended by author to determine paste flow behavior. The tests could be conducted using small scale pipe loops (20 to 50 mm) in a laboratory, or full scale loops at the mine site or at a specially constructed test loop. The advantages of small scale tests are significantly lower material requirement, lower cost, greater instrumentation accuracy and availability of carefully controlled experimental conditions. The paper essentially provides a rational basis for analyzing paste flows based on technology developed for stabilized slurries. The pseudo shear diagram provides a simple technique for scaling test loop data without requiring complex rheological characterization as reported by Cooke (2001).

The study of Vickrey and Boldt (1989), indicated that paste with low slumps required higher pumping pressure, whereas, the pastes with high slumps had a greater tendency to cause hammering at the pump, and also the high slump pastes settled when left stationary in the pipe line. These observations were made during pump tests in loops using cemented and uncemented pastes with slumps values ranging from 10.8 to 17.8 cm based on the 30.5 cm standard slump cone experiment. Tenbergen (2000), studied certain aspects and characteristics of paste backfilling operation. He studied the paste flow behavior of mill tailings and aggregate material and presented the slump test results in terms of solid concentration, compressive strength, and pressure loss. It was noticed that the slump value was more significant than the solids content in determining flow behaviour, and than higher pressure losses using transportation resulted from low slump tailings.

# CHAPTER 3

**MECHANISM AND MATERIAL**

**SAMPLE COLLECTION**

**CHARACTERIZATION OF FLY ASH**

**PROPERTIES OF FLY ASH SLURRY**

**FLUENT AND GAMBIT SOFTWARE**

## **SAMPLE COLLECTION:**

The sample collection of different types of ashes such as fly ash, bottom ash and pond ash has different procedures. The fly ash and the bottom ashes are generated at the power plant and can be collected directly from the discharge points. In most of the power plants sampling pipes are provided at places near the discharge point or near the storage point for collection of ash samples. The sample can be directly collected into a bucket or any other container and can be suitable packed for transportation.

### **Sample from RSP, CPP I**

- The sample was collected from: Rourkela Steel Plant, Captive Power plant
- The sample was collected from near the hopper of the power plant.
- The fly ash sample collected was dark grey in color.
- The sample was collected in a sack and wrapped immediately to avoid addition of moisture.
- The sample collected are then transported by a suitable means and stored in a dry place away from direct sunlight.

## **CHARACTERIZATION OF FLY ASH**

The study of the physicochemical and engineering properties of fly ash is necessary to understand the variation in the properties of fly ash. In the Indian context, in order to utilize the same as large volume backfill media. In addition to this the study is required to establish properties such as permeability, particle size distribution, and morphological characteristics of the fly ash which influence the settling behaviour and flow properties during hydraulic transportation. In present context experimental studies are conducted for different Indian fly ash samples to determine the properties of importance for mine void filling and to understand the variability among these properties.

## **PROPERTIES OF FLY ASH:**

### **MOISTURE CONTENT:**

Moisture content is reported either on a dry weight basis or total weight basis. This is an important distinction to make.

About 1 g of finely divided powdered air dried fly ash sample is weighed in a crucible. The crucible is placed inside an electric hot air oven, maintained at 105° C. The crucible is allowed to remain in the oven with lid open for 24 hours and then taken out (with a pair of tongs), cooled in a desiccator and weighed. Loss in weight is reported as moisture (on % basis).

Percentage of moisture = (loss in weight / wt of coal taken) \* 100

### **DENSITY:**

There are three density involved in the specification of fly ash slurry: namely the density of the solid particles, the density of the suspending medium i.e. water and the density of the slurry itself. The density of the solid and the suspending medium can be evaluated by conventional methods.

### **SPECIFIC GRAVITY:**

Specific gravity is one of the important physical properties needed for the use of coal ashes for geotechnical and other applications. In general, the specific gravity of coal ashes varies around 2.0 but can vary to a large extent (1.6 to 3.1). Because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities. The reduction in unit weight is of advantage in the case of its use as a backfill material for retaining walls since the pressure exerted on the retaining structure as well as the foundation structure will be less.

### **VISCOSITY:**

An important effect of the addition of solid particle to a fluid is its influence on the system viscosity. The presence of the particle invariably increases the suspension viscosity to a value

greater than that of the fluid and in many cases results in a suspension which is non-Newtonian in character.

The field suspension viscosity has been one upon which a certain amount of controversy. The concept of suspension viscosity is in itself difficult. The viscosities of slurry of uniform spherical particles are usually Newtonian in character. This type of system is important since its viscosity represents the a minimum value of the viscosity of the non-Newtonian fluid.

The viscosity of the suspension is given by:

$$\mu_m/\mu_0 = 1 + 2.5\phi$$

where  $\mu_m$  = viscosity of suspension

$\mu_0$  = viscosity of water

$\phi$  = volume concentration of solid

## **pH**

In general, fly ash can be classified as an amorphous ferro-alumino silicate mineral. The amorphous iron aluminium oxides as well as manganese oxides present on the surface of fly ash particles act as a sink, adsorbing the trace elements. It is this quantity of trace element which is available for leaching. The degree of solubility of these oxide sinks determines the release of the elements associated with them into the aqueous medium.

The pH of the aqueous medium affects the solubility of these oxides and hence their physico-chemical characteristics. Further, the mobilization of trace elements in aqueous medium is often regulated by the solubility of hydroxide and carbonate salts which also depends on the pH of the aqueous media.

The investigations carried on Indian coal ashes at IISc show that fly ash has higher pH values compared to pond and bottom ashes. The fly ash with higher free lime and alkaline oxides exhibits higher pH values. Since all the coal ashes tested are nearly alkaline, they can be used in reinforced cement concrete which will be safe against corrosion.

## **PERCENT SOLIDS:**

Percent solids = mass of solids/(mass of solids+water).

Small changes in pulp density can result in a dramatic increase in the line pressure particularly for paste backfills.

## **GRAIN SIZE:**

The grain size distribution will determine the permeability of the fill. The higher the "slimes" content, the lower the percolation rate. Grain size distribution affects the pumpability of fill. In the case of hydraulic fill, the larger the grain size the faster the terminal settling velocity. The velocity of the slurry in the pipe must exceed this settling velocity.

Grain size distribution affects void ratio and ultimately the strength of the fill. The lower the void ratio, higher the strength. A more uniformly graded fill has a lower void ratio.

## **RHEOLOGY:**

Rheology is the study of the shear strength behavior of liquids. Viscosity is a measure of the shear strength or the resistance to movement between different layers in a fluid or mixture. In concrete terminology this is also known as the workability. The viscosity of a paste mixture is difficult to predict and is influenced by many factors including: pulp density, grain size, mineralogy, and grain shape. The concrete slump test has generally been used as a measure of the viscosity of paste mixtures.

Paste mixtures behave as non-Newtonian fluids, that is, they do not exhibit constant viscosity with variation in flow rate. The yield stress of a paste is greater than zero before flow commences. Research and experience to date, indicates that paste backfill can be considered to be a Bingham plastic fluid, exhibiting constant viscosity with increased velocity, once the yield stress has been overcome. It can also be a pseudo-plastic fluid, exhibiting decreasing velocity as velocity increases



## **PARTICLE SIZE DISTRIBUTION:**

In discussions about rockfill, the coarse size fraction generally refers to the material from greater than 10 mm to the top size of 100-150 mm. The fine aggregate is considered to be the material less than 10 mm in size. The fine aggregate should make up about one quarter to one-third of the total aggregate weight.

The ideal grading that results from minimizing the void space is given by

$$P(u) = 100(u/u_{\max})^{0.5}$$

where,

$P(u)$  = probability of material finer than sieve opening  $u$

$u$  = opening size , mm

$u_{\max}$  = maximum particle size

## **FLUENT & GAMBIT SOFTWARE:**

The hydrodynamics of two-dimensional slurry were studied computationally. The liquid flow in a pipe is modeled by computational fluid dynamics in which various parameter i.e. mass flow, velocity etc are treated mathematically as interpenetrating continua & solved.

The following aspect has been achieved in this semester:

- A thorough literature review has been taken.
- The numerical modeling software FLUENT AND GAMBIT are being learned
- Fly ash samples were collected from local source.

## **GAMBIT:**

A geometric modeling and grid generation tool often shipped with FLUENT. GAMBIT allows users to create their own geometry or import geometry from most CAD packages. It can automatically mesh surfaces and volumes while allowing the user to control the mesh through the use of sizing functions and boundary layer meshing.

## **FLUENT:**

The **FLUENT** solver has the following modeling capabilities relating to pipe flow:

- 2D planar, 2D axisymmetric, 2D axisymmetric with swirl (rotationally symmetric), and 3D flows
- Quadrilateral, triangular, hexahedral (brick), tetrahedral, prism (wedge), pyramid, and mixed element meshes
- Steady-state or transient flows
- Incompressible or compressible flows, including all speed regimes
- Inviscid, laminar, and turbulent flows
- Newtonian or non-Newtonian flows
- Heat transfer, including forced, natural, and mixed convection, conjugate (solid/fluid) heat transfer, and radiation
- Free surface and multiphase models for gas-liquid, gas-solid, and liquid-solid flows

# **CHAPTER 4**

## **RESULTS AND DISCUSSIONS**

From the analysis of slurry flow pattern by experiments and fluent CFD simulation, we can conclude the followings:

- From the compositions of fly ash sample collected, it can be concluded that the fly ash sample belongs to ASTM class F.
- As per the pH content of the fly ash samples, it was found that RSP CPP 1 sample had high CaO content.
- The moisture content of the samples were found out to be around 0.703% (annexure 1,table 1) indicating that all the moisture have been evacuated and they are suitable for the construction works etc.
- The wet density of the samples was found out to be 1.6(annexure 1, table 2).
- The specific gravity of the RSP CPP 1 sample was 2.51(annexure 1, table 3).
- The simulation of fly ash slurry obtained by fluent CFD package for homogenous flow depict a laminar flow across the whole length of pipe without much variation in flow parameter.(annexure 3)
- The settling rate patterns for heterogeneous flow obtained from the FLUENT (taking phase 1 as water and phase 2 as fly ash), we can say that raw fly ash without any additive settles at 40%.(annexure 4).
- The result obtained by varying the percentage of additives i.e. cement(0 to 8 percent),lime (0 to 6 percent), and gypsum (1 to 4 percent) are as followed(annexure 2):
  - It was found that for raw fly ash,the pH was varied from 5.5 to 6.
  - Keeping cement percentage to zero, the pH of the fly ash sample was found to vary from 5.6 to 7.9.
  - As the cement percent increases the pH increases to 11.43 which is maximum and obtained by adding 4% lime, 4% gypsum and 8% cement which is the optimum value of pH ,since as pH value decreases after addition of further 2 percent lime.
  - It was found that the pH was found to be highest with the percentage of 4% lime, 4% gypsum and 8% cement, so for the work requiring high strength.

# **CHAPTER 5**

**CONCLUSION**

**SCOPE FOR FURTHER STUDY**

## **CONCLUSION:**

The other major concern is the non-availability of sand for back filling the underground mine voids in future. In view of future, the objective is to study properties of the fly ash as an alternative to sand as a back filling material. With the promise of the of the paste backfill technology the transportation of fly ash is a major problem due to its complex flow behavior. These complexities may be caused by interactions between solid particles forming the internal structure, particle size distribution, and non-spherical characteristics of suspended particles.

An effort is made in the present study to generate data on physicochemical characteristics and settling rate characteristics of fly ash samples collected. Simulations on flow behavior, using computational fluid dynamics software, of fly ash are conducted.

The conclusion may be summarized as:

- From the compositions of fly ash sample collected, it can be concluded that the fly ash sample belongs to ASTM class F.
- The settling rate patterns obtained from the FLUENT, we can say that raw fly ash without any additive settles at 40%. However from the settlement curve, we cannot predict solid-liquid separation characteristics using additives or which may requires more specific data and the study on the mechanism of chemical reaction of fly ash with different additives.
- The velocity of the slurry point out that fly ash alone does not exhibit tendency to flow beyond 40% solids concentration by weight in the mixture which may be possible with high pressure difference but economic consideration has to be taken into account.
- The model with flow velocity and pattern of the slurry shows that in a horizontal pipe the increase in solids weight content results in a dramatic reduction in the velocity of flow.
- Huge amount of fly ash (120 million tones) is available for mine void filling and frequently in the vicinity of mines. Only consideration is to utilize this easily available material for filling requirements through best possible techniques without affecting the quality of mining and environment. Present study has been a comprehensive effort to some degree to provide useful information in this direction in the Indian context.

## **SCOPE FOR FURTHER STUDIES**

- Viscosity is an important parameter in the study of the rheological behavior of slurry medium. In the present study although viscosity is estimated by an indirect approach, the direct measurement of viscosity (may be through the rotational viscometer) can help in bringing out proper correlations of viscosity with other flow parameters.
- High densities slurries (above 50%) could not be studied due to limitations of gravitational head created in the present setup. However densified slurry transportation of fly ash requires investigation.
- Hydraulic conveyance of powdery solids in the form of pellet is known to benefit the transportation process. Scope exists to examine the aspects of pelletization, pellet strength improvisation to withstand transportation related stresses and to study the effects of transportation of fly ash pellet on pipe wear and energy consumption.
- Lab tests involving slurry pumping mechanism and pipelines of varying dimensions and length provide more practical and readily applicable information to the industry. Research in loop tests using the fly ash or fly ash sand mixture is desirable.

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## ANNEXURE 1

### TABULATION:

**TABLE 1 (MOISTURE CONTENT OF FLY ASH):**

Weight of empty crucible (gm)	Weight of sample (gm)	Weight of crucible and sample before heating (gm)	Weight of crucible and sample after heating (gm)	Moisture content(%)	Average Moisture content(%)
15.136	1.002	16.138	16.130	0.707	0.703
14.972	1.004	15.974	15.968	0.719	
16.756	1.003	17.759	17.752	0.683	

**TABLE 2 (DENSITY OF FLY ASH):**

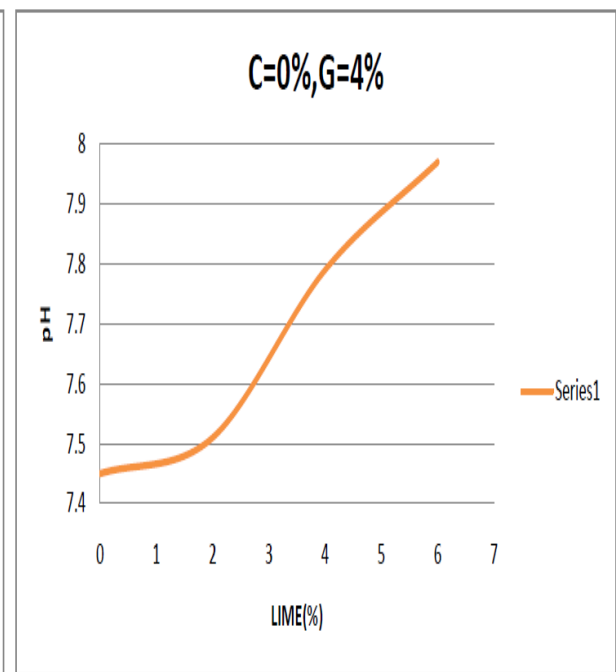
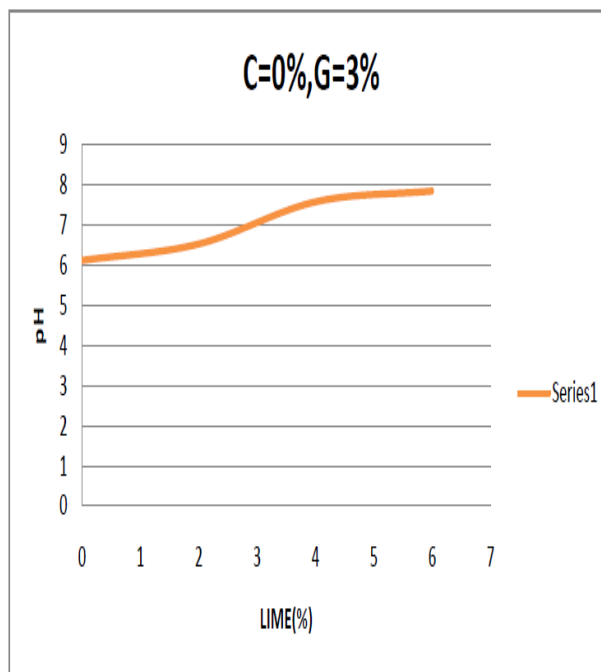
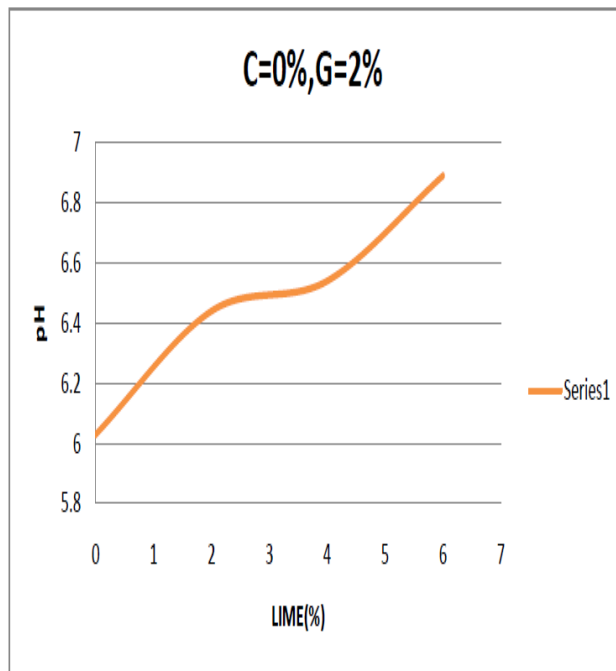
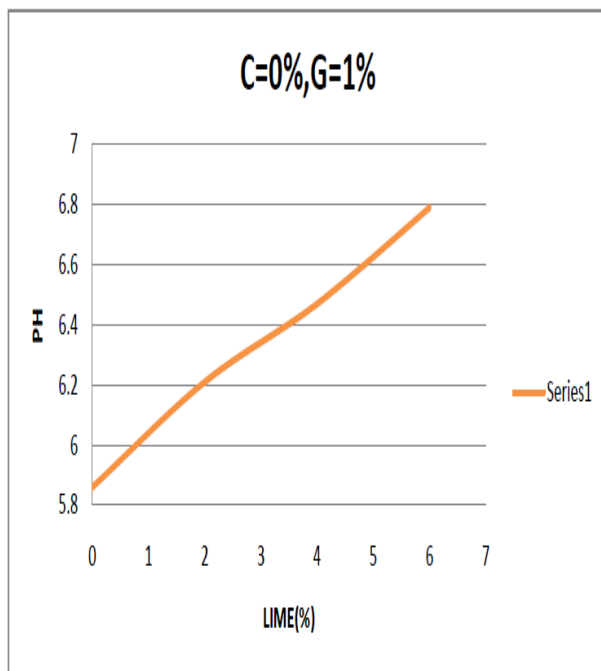
Weight of sample (gm)	Initial volume (ml)	Final volume (ml)	Change in volume (ml)	Density (gm/cc)	Average Density (gm/cc)
5.002	50	50.3	0.3	1.6	1.6
5.001	50	50.3	0.3	1.6	
5.003	50	50.3	0.3	1.6	

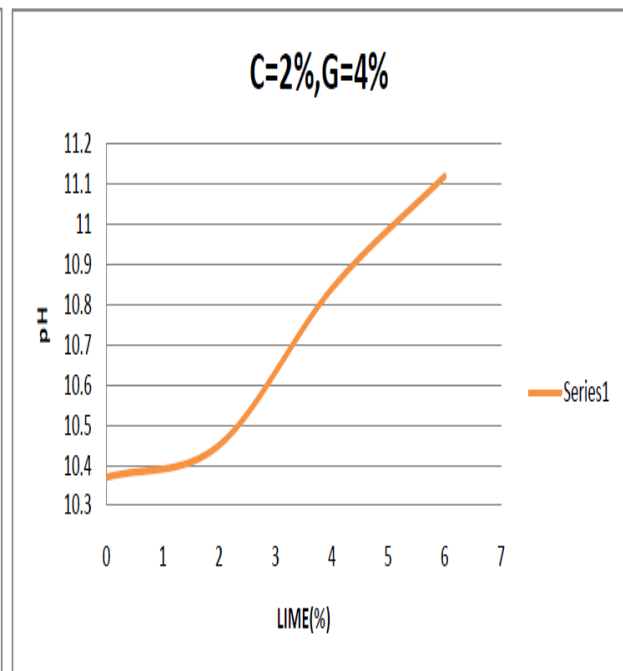
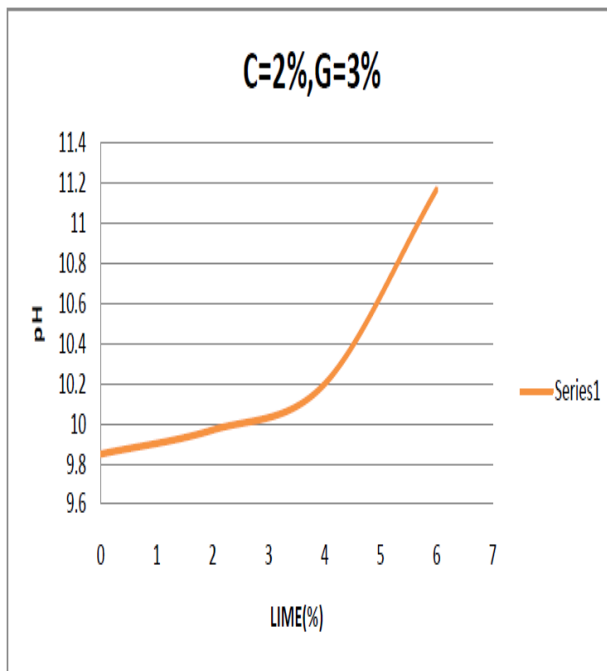
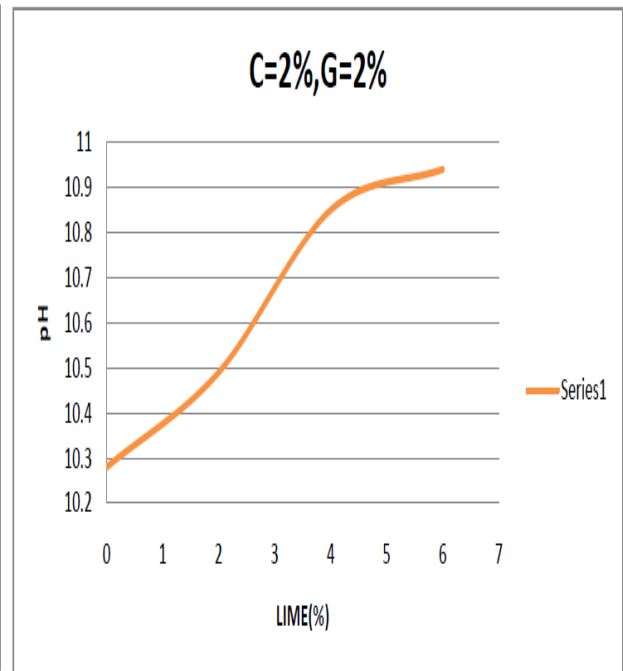
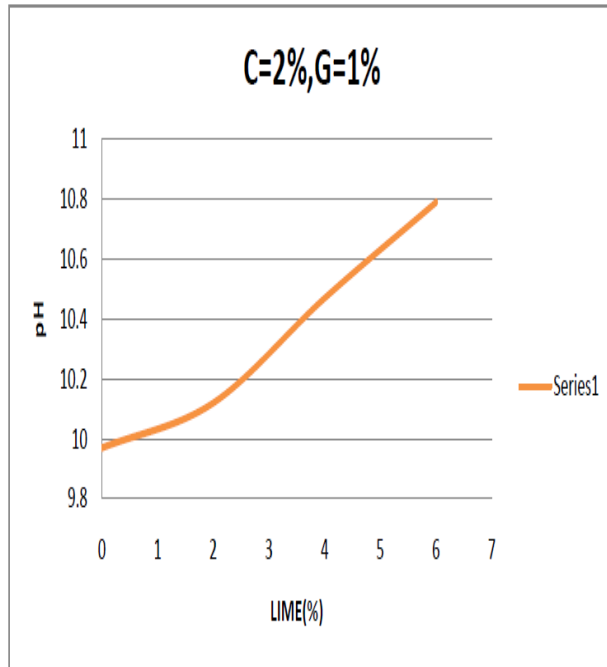
**TABLE 3(SPECIFIC GRAVITY OF FLY ASH):**

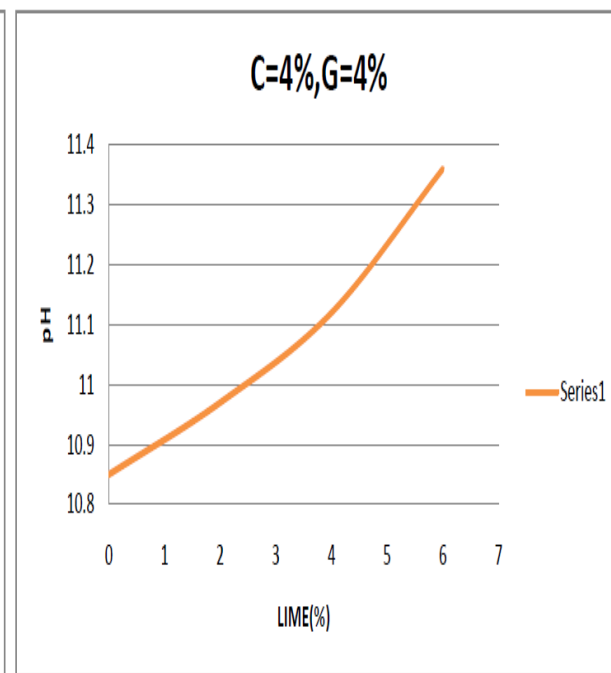
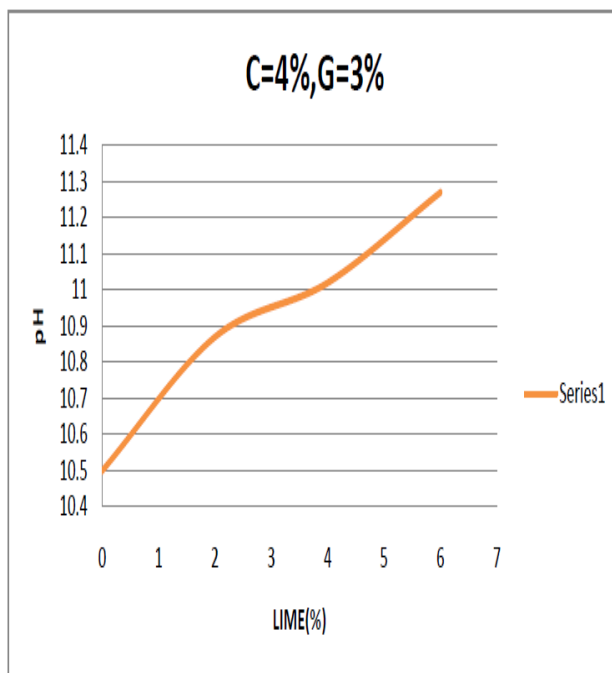
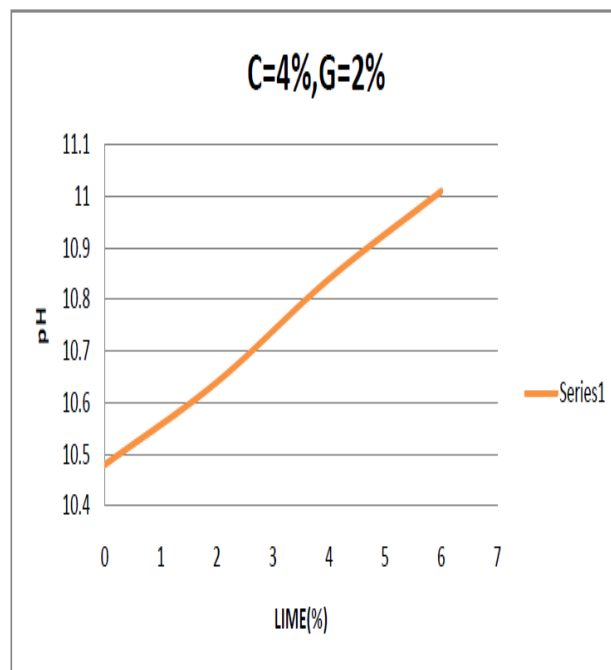
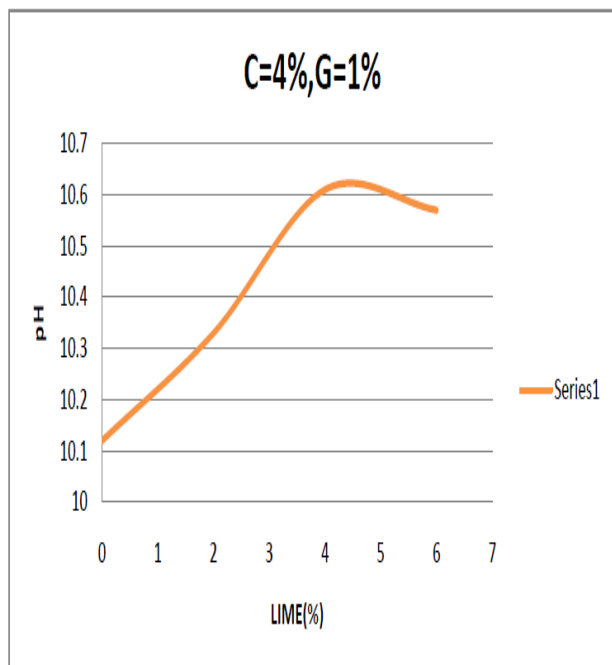
Weight of empty flask (gm)	Weight of flask + kerosene(gm)	Weight of sample (gm)	Weight of flask + kerosene+fly ash (gm)	Kerosene displaced	Specific gravity	Average Specific gravity
15.165	51.139	1.000	65.916	0.388	2.577	2.51
15.166	52.047	1.001	66.815	0.367	2.52	
15.174	52.120	1.003	66.884	0.410	2.44	

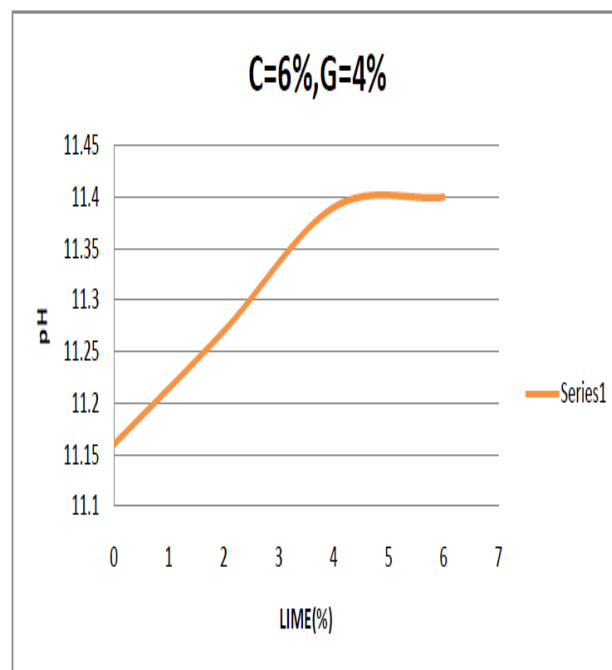
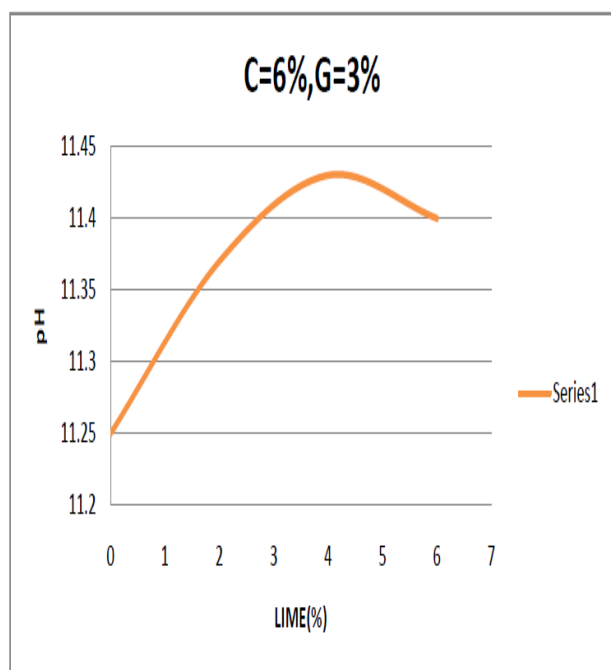
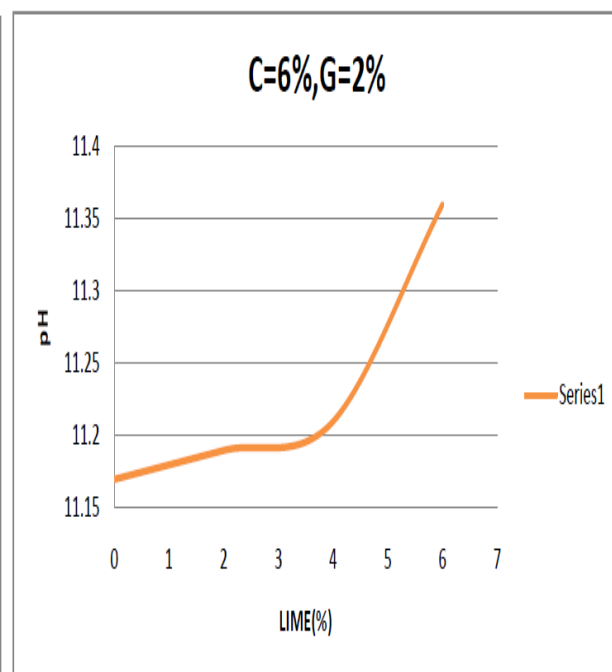
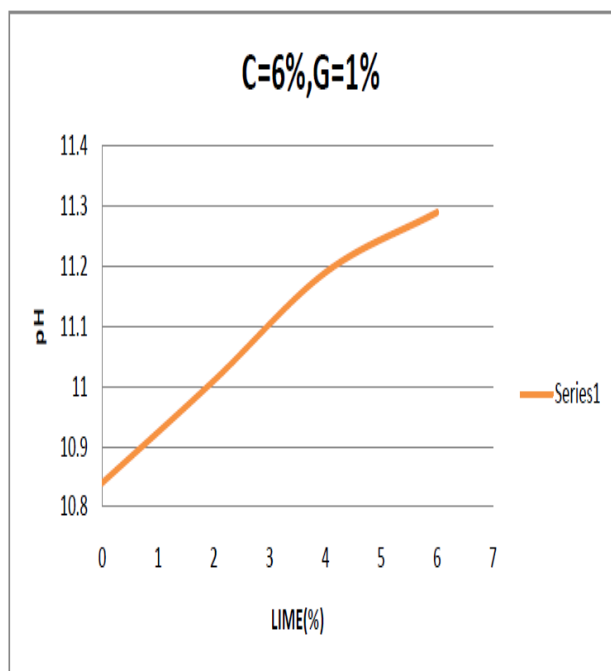
## ANNEXURE 2

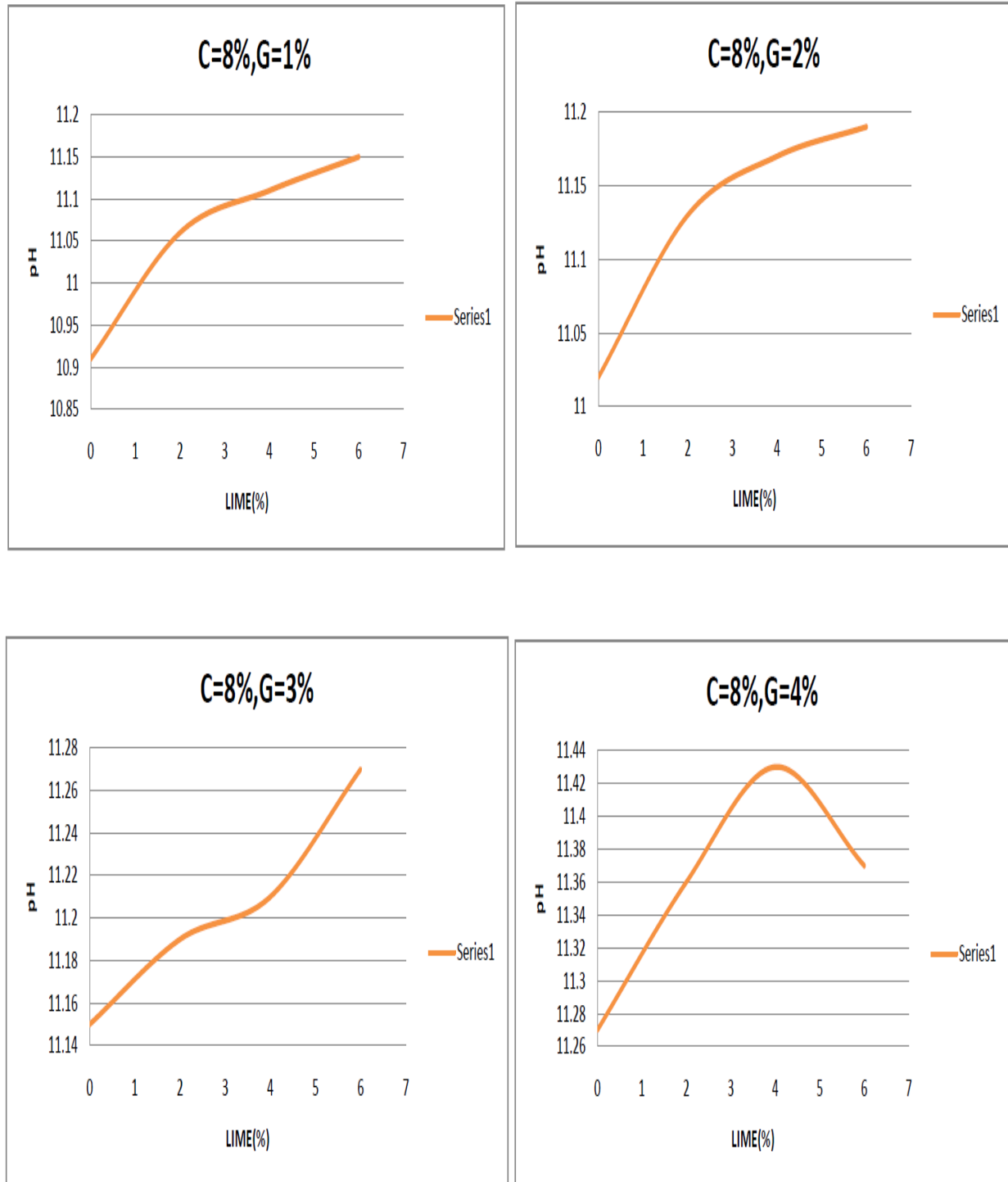
### VARIATION OF PH OF FLY ASH WITH DIFFERENT CONCENTRATIONS OF LIME, GYPSUM AND CEMENT.









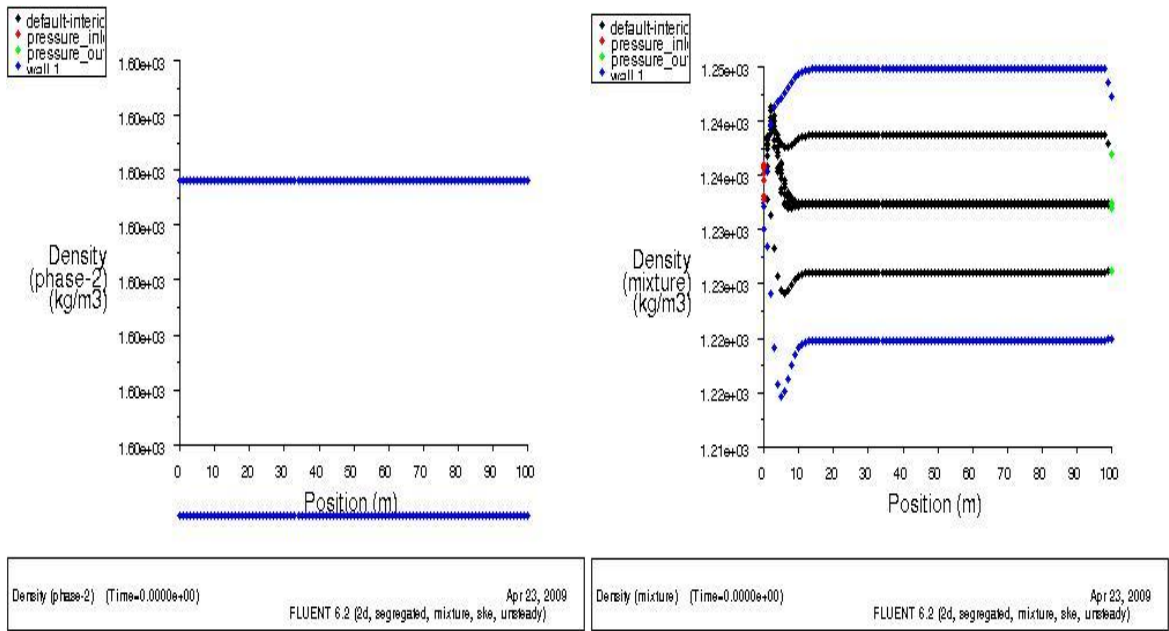


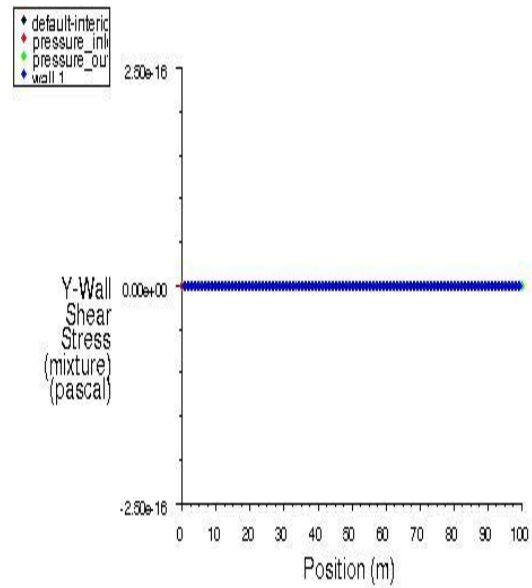
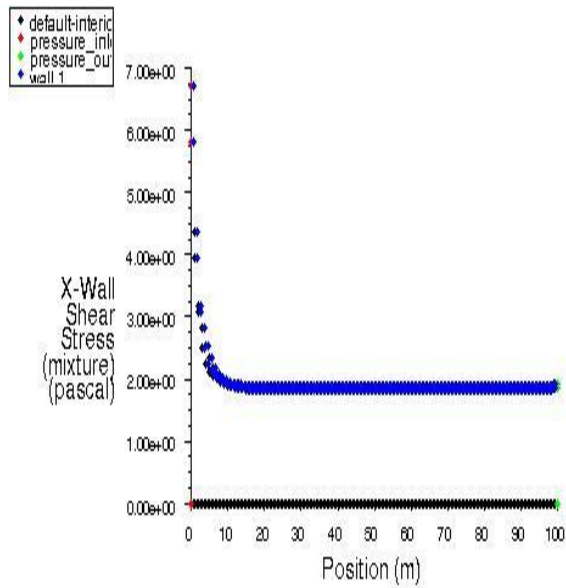
**Figure 3.1 Variation of pH of Fly Ash with different concentrations of lime, gypsum and cement.**

# ANNEXURE 3

## SIMULATION: using FLUENT CFD package

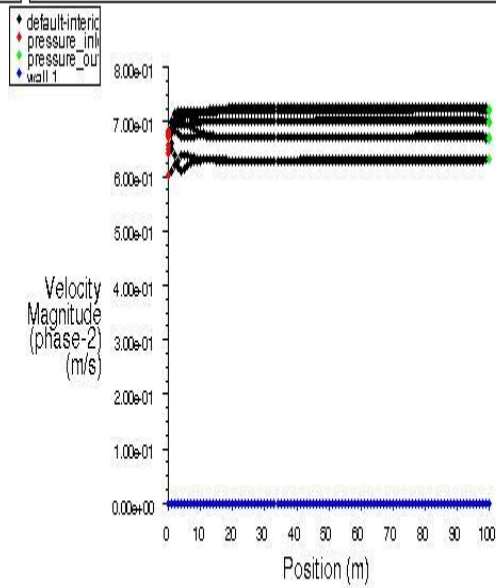
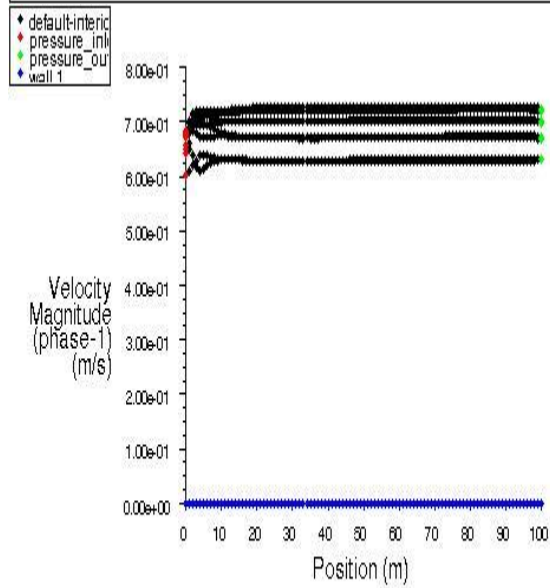
### GRAPHS: STEADY FLOW(TWO PHASE):





X-Wall Shear Stress (mixture) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

Y-Wall Shear Stress (mixture) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



Velocity Magnitude (phase-1) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

Velocity Magnitude (phase-2) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



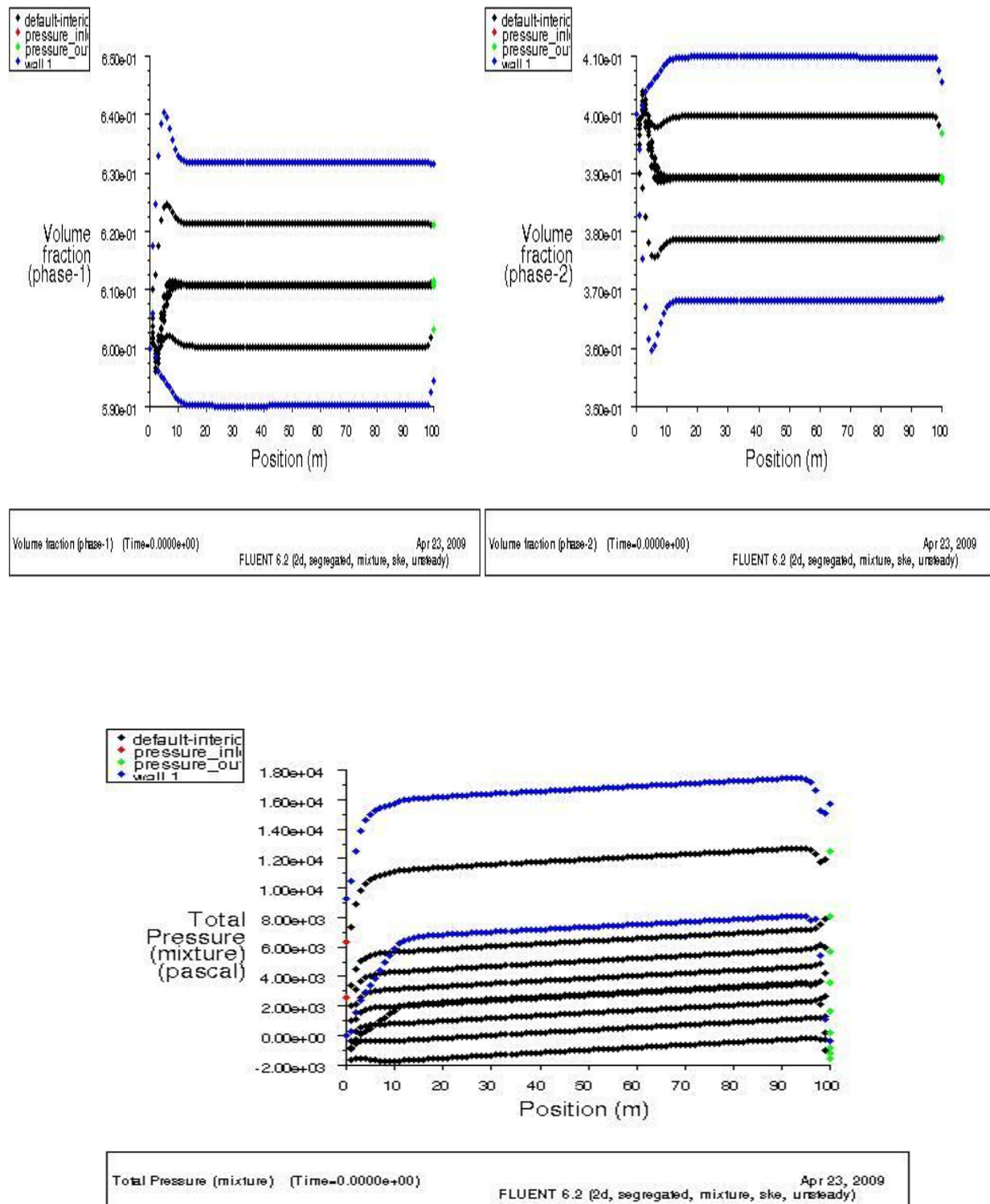
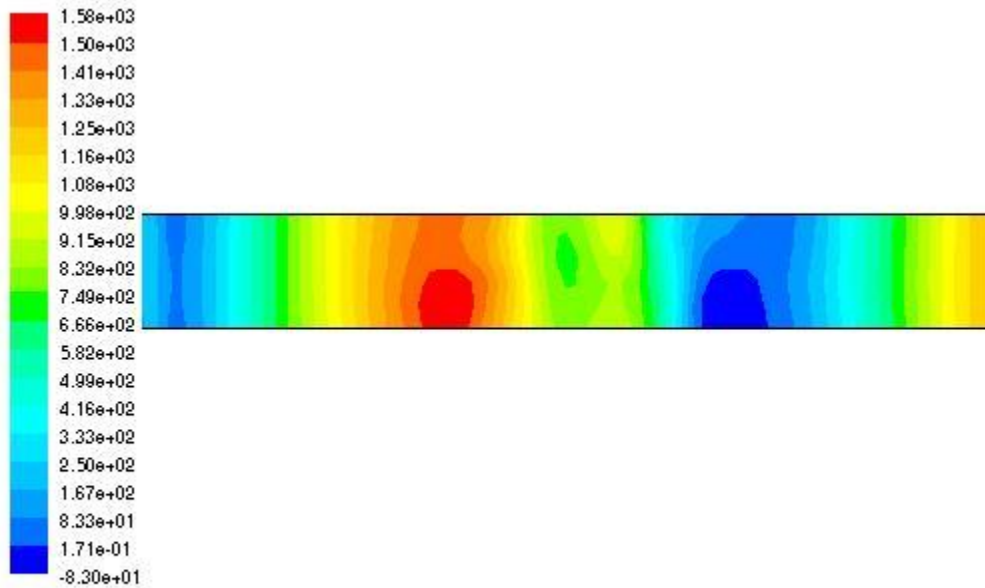


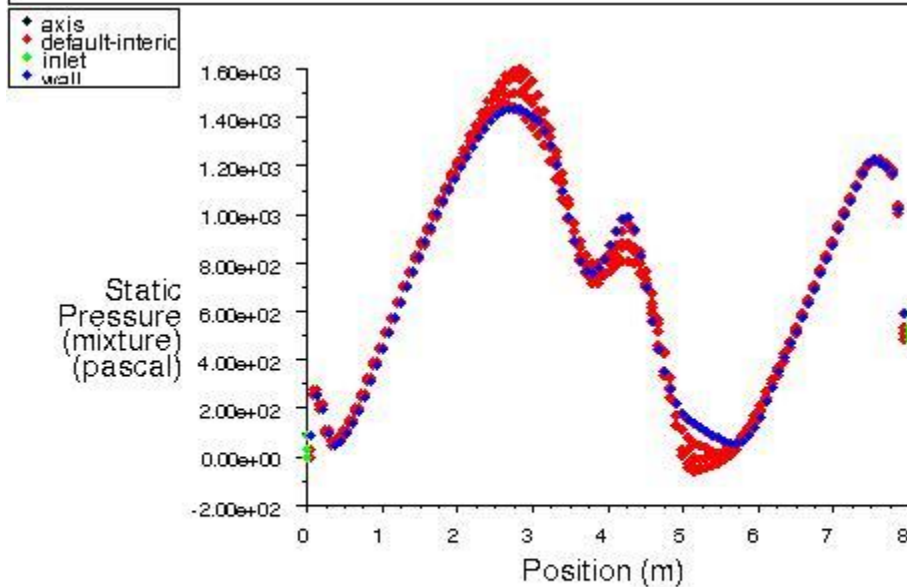
Figure 4.1 graphs for variation of flow with different position of pipe for homogeneous continuum

## ANNEXURE 4

### Heterogenous flow(multiphase)

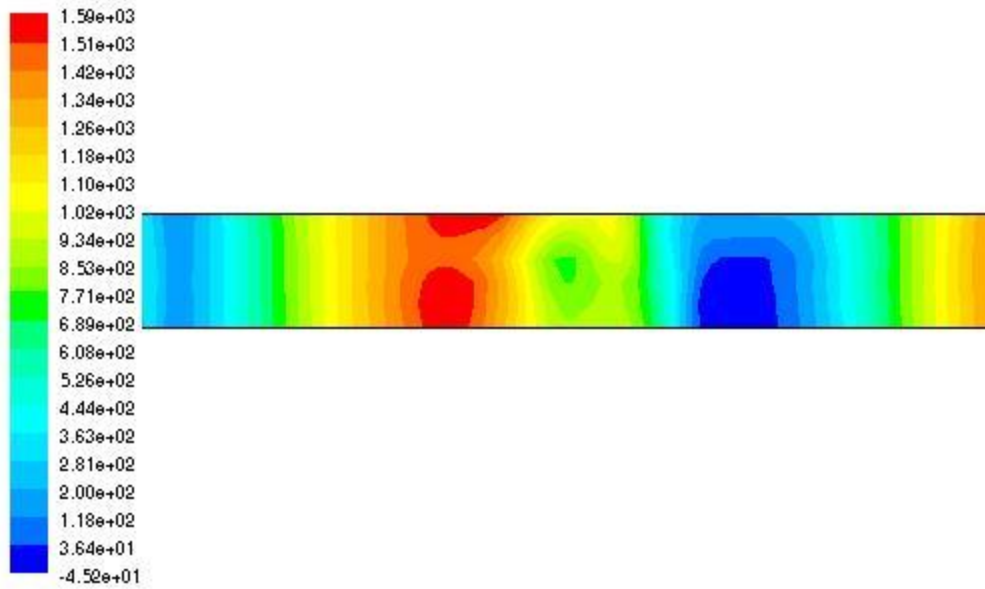


Contours of Static Pressure (mixture) (pascal) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

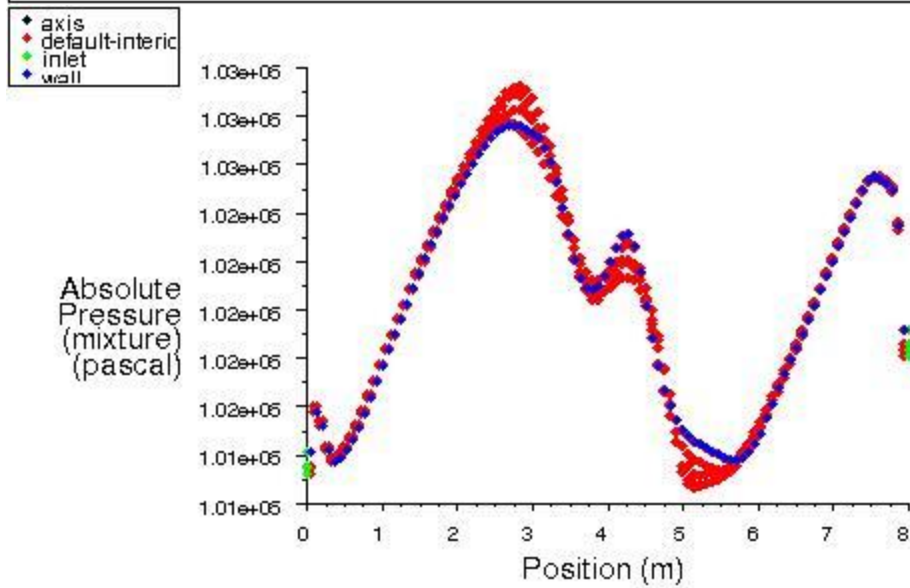


Static Pressure (mixture) (Time=0.0000e+00)

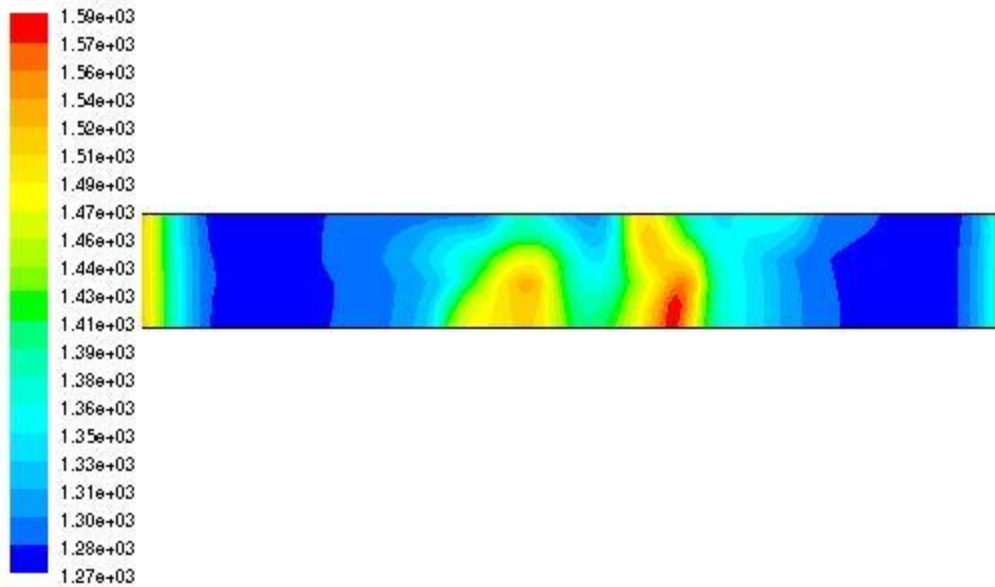
Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



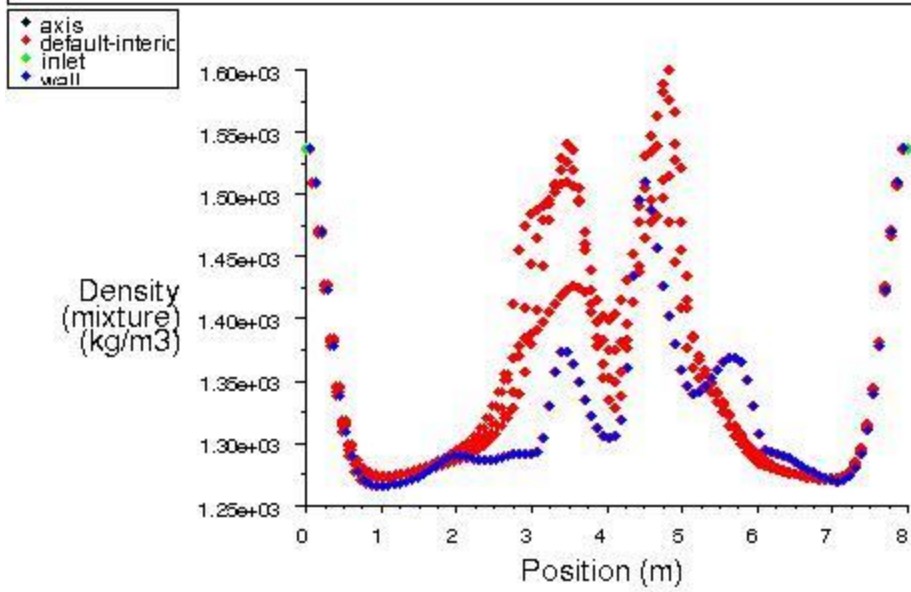
Contours of Total Pressure (mixture) (pascal) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



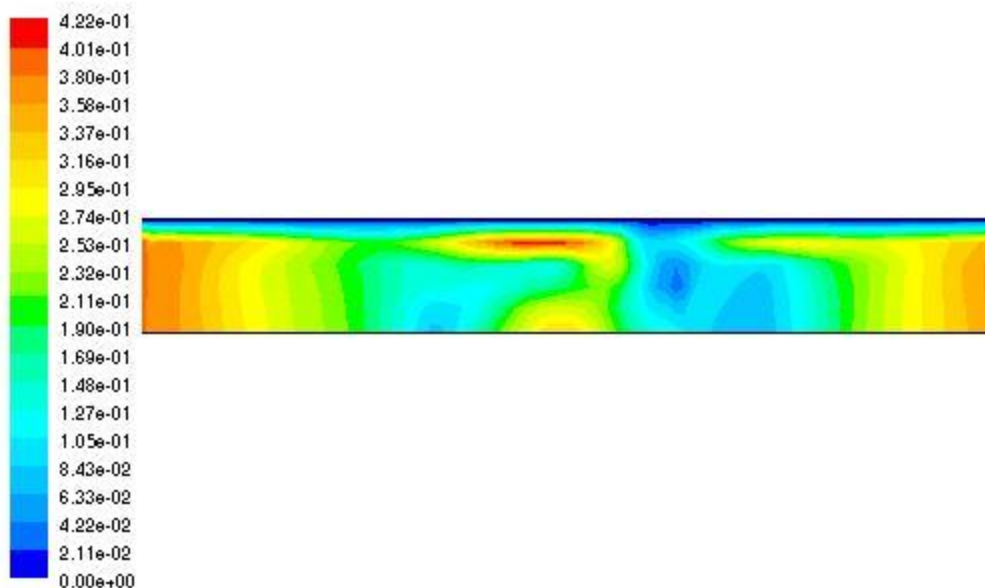
Absolute Pressure (mixture) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



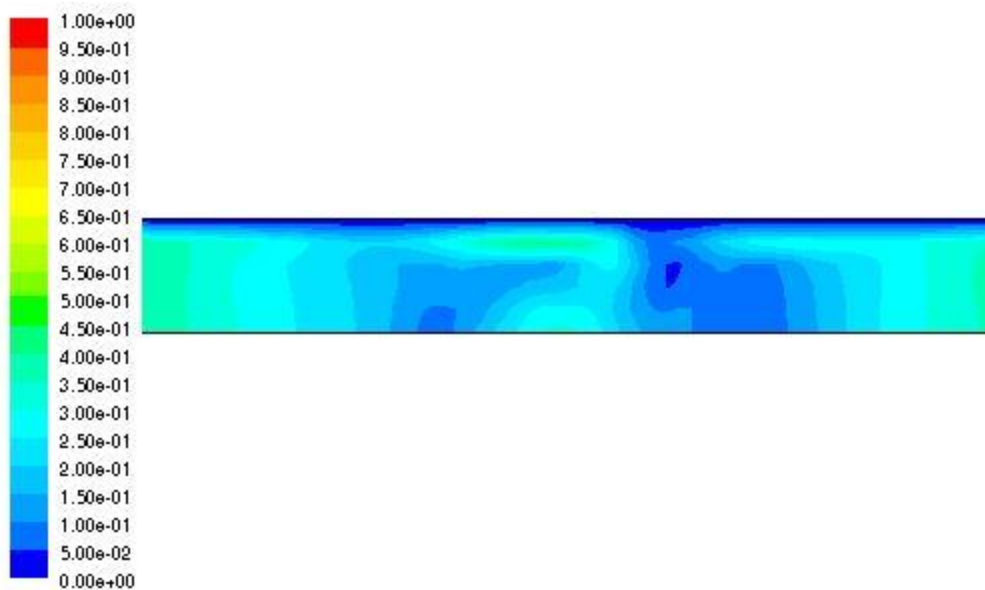
Contours of Density (mixture) (kg/m3) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



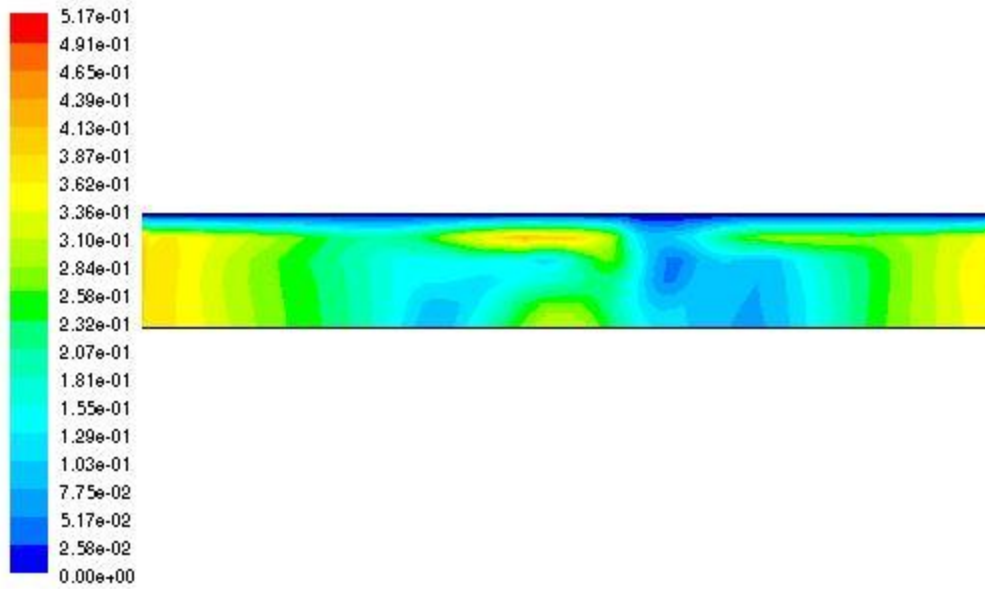
Density (mixture) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



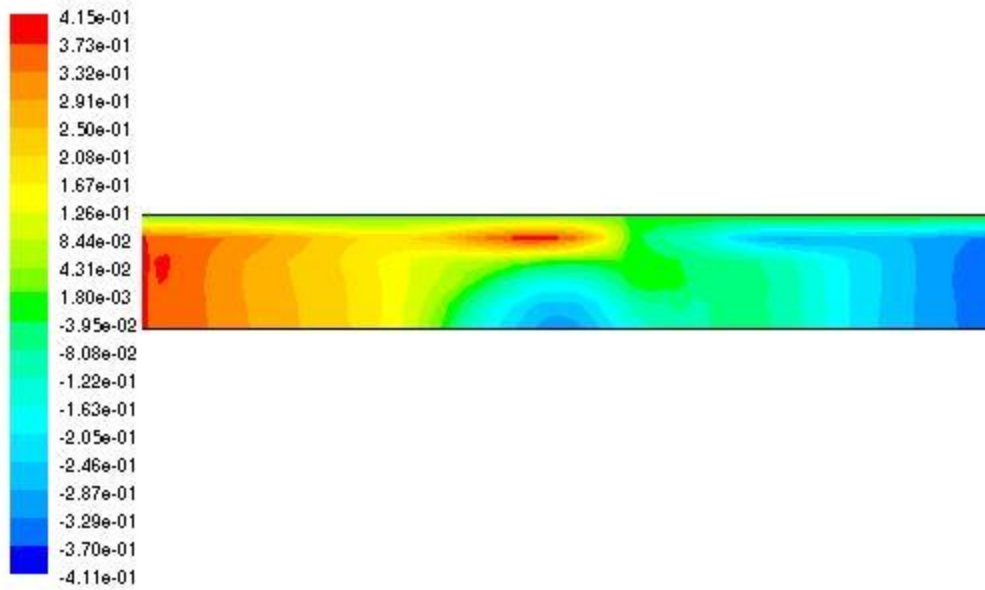
Contours of Velocity Magnitude (phase-1) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



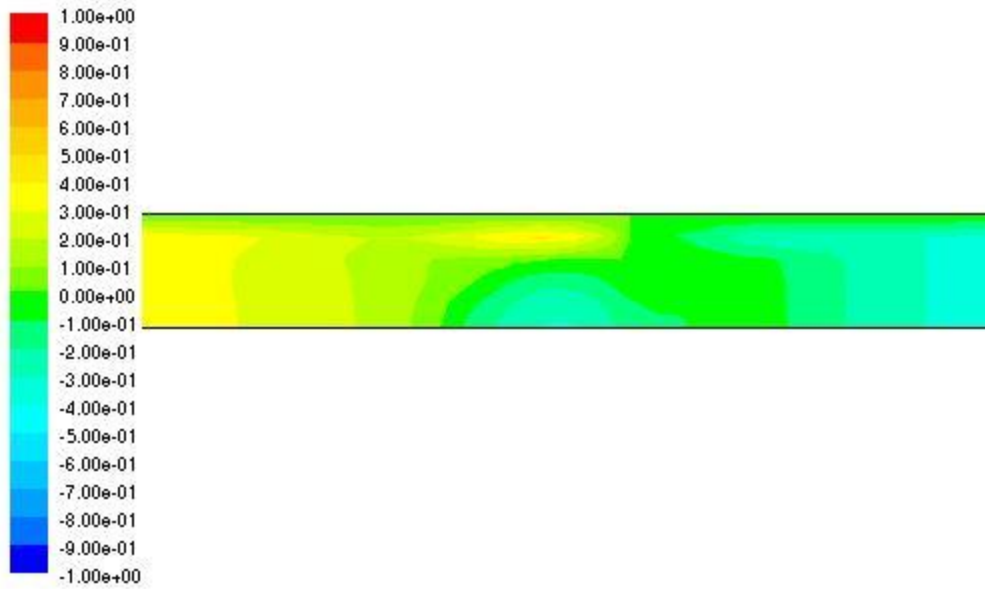
Contours of Velocity Magnitude (phase-2) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



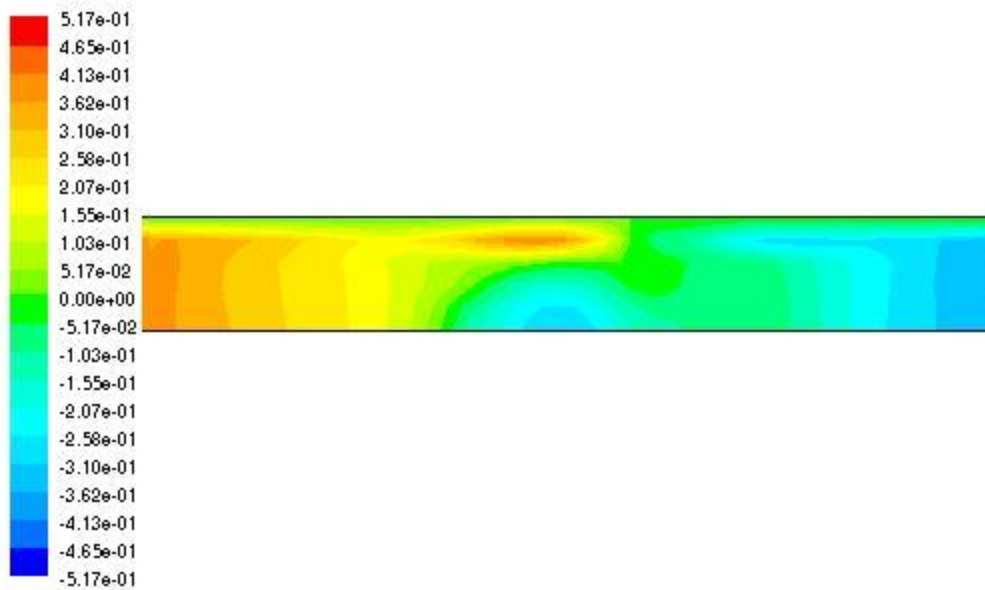
Contours of Velocity Magnitude (mixture) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



Contours of X Velocity (phase-1) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

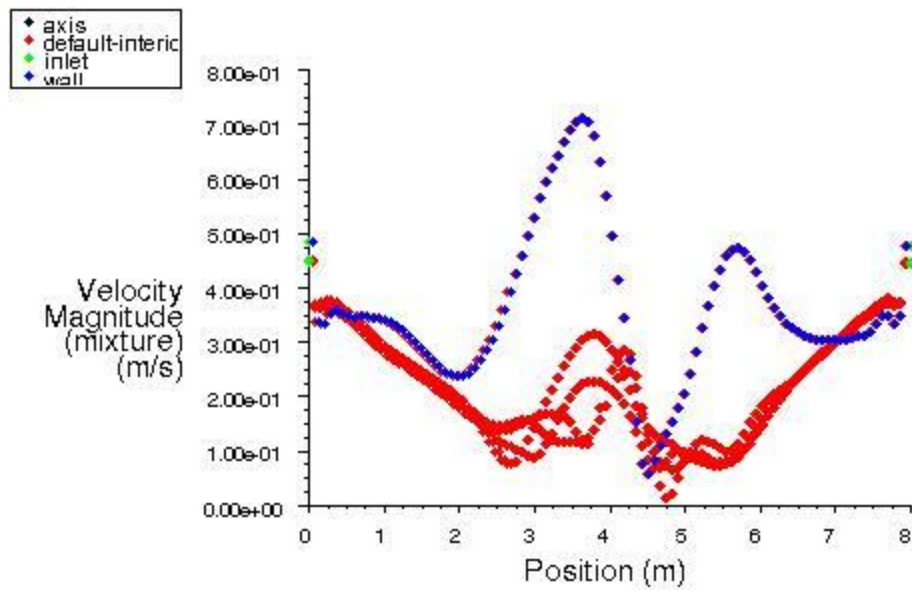


Contours of X Velocity (phase-2) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



Contours of X Velocity (mixture) (m/s) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

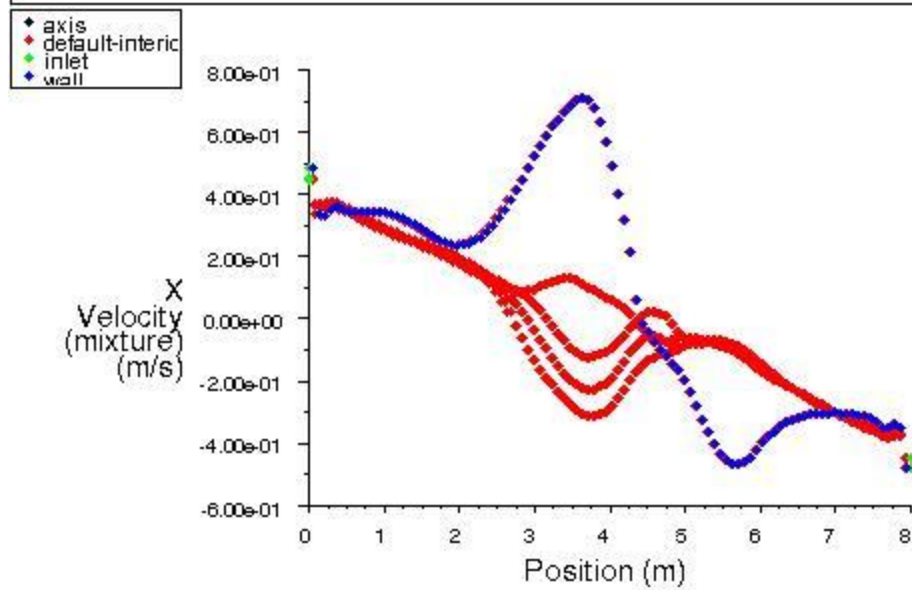




Velocity Magnitude (mixture) (Time=0.0000e+00)

FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

Apr 23, 2009

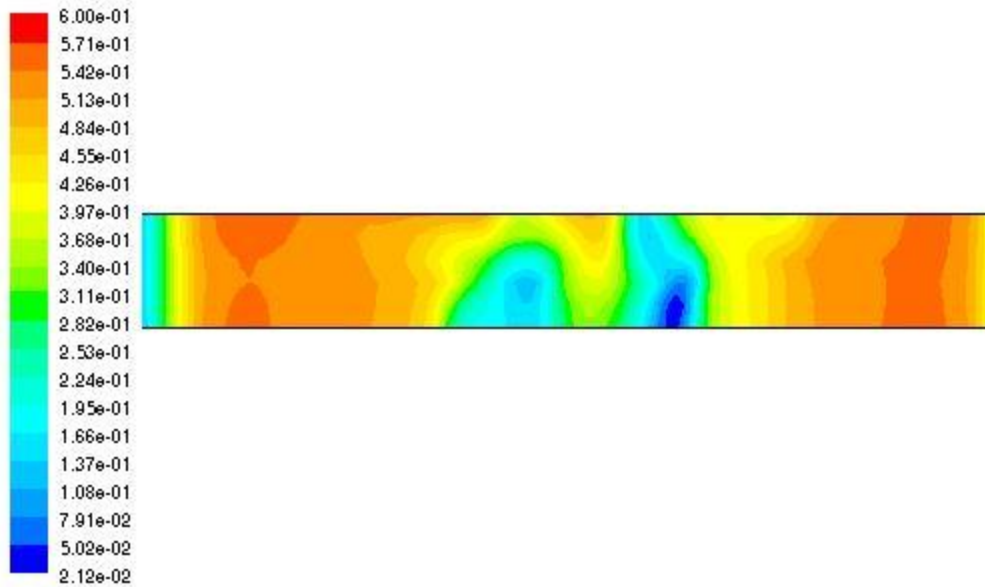


X Velocity (mixture) (Time=0.0000e+00)

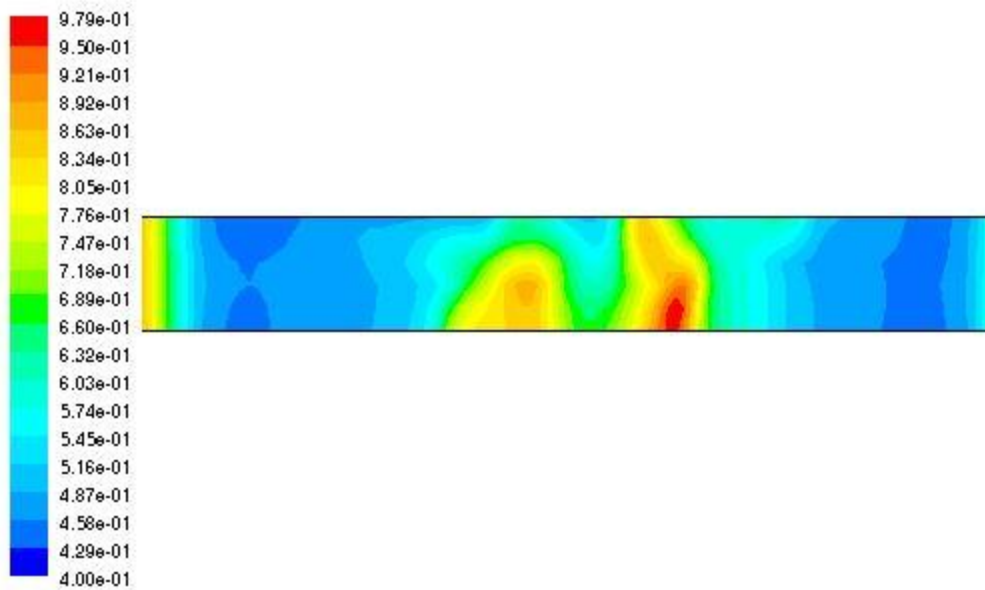
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

Apr 23, 2009





Contours of Volume fraction (phase-1) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)



Contours of Volume fraction (phase-2) (Time=0.0000e+00) Apr 23, 2009  
FLUENT 6.2 (2d, segregated, mixture, ske, unsteady)

Figure 4.2 graphs for variation of flow with different position of pipe for heterogeneous continuum

## ANNEXURE 5

### **SIMULATION RESULTS: input data:**

#### **FLUENT**

Release: 6.2.16

Model	Settings
Space	2D
Time	Unsteady ( 1st-Order Implicit)
Viscosity	Laminar
Heat Transfer	Disabled
Solidification and Melting	Disabled
Species Transport	Disabled
Coupled Dispersed Phase	Disabled
Pollutants:	Disabled
Soot:	Disabled

#### **BOUNDARY TYPES:**

Zones Name	id	type
fluid	2	fluid
wall	3	wall
outlet	4	pressure-outlet
inlet	5	velocity-inlet
default-interior	7	interior

## BOUNDARY CONDITIONS:

Fluid Condition	Value
Material Name	Air
Specify source terms	No
Specify fixed values	No
Fixed Values	0
Motion Type	0
X-Velocity of Zone	0
Y-Velocity of Zone	0
Rotation speed	0
X-Origin of Rotation-Axis	0
Y-Origin of Rotation-Axis	0
Deactivated Thread	No
Porous zone	No
Porosity	1
Wall Condition	Value
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone	Yes
Apply a rotational velocity to this wall	No
Velocity Magnitude	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Define wall velocity components	No
X-Component of Wall Translation	0
Y-Component of Wall Translation	0
Rotation Speed	0

X-Position of Rotation-Axis Origin	0
Y-Position of Rotation-Axis Origin	0
X-component of shear stress	0
Y-component of shear stress	0

Outlet Condition	value
Gauge Pressure	18000
Backflow Direction Specification Method	1
is zone used in mixing-plane model	No
Specify targeted mass-flow rate	No
Targeted mass-flow	1

Inlet Condition	value
is zone used in mixing-plane model	no

## **MATERIAL PROPERTIES:**

### **MATERIAL :FLY ASH(SOLID)**

Property	Units	Method	Value(s)
Density	kg/m3	constant	1800
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

### **MATERIAL: AIR (FLUID)**

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43

Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
Degrees of Freedom		constant	0

### **MATERIAL: WATER-LIQUID (FLUID)**

Property	Units	Method	Value(s)
Density	kg/m <sup>3</sup>	constant	998.20001
Cp (Specific Heat)	j/kg-k	constant	4182
Thermal Conductivity	w/m-k	constant	0.6
Viscosity	kg/m-s	constant	0.001003
Molecular Weight	kg/kgmol	constant	18.0152
Degrees of Freedom		constant	0

### **MATERIAL: SOLID (FLUID)**

Property	Units	Method	Value(s)
Density	kg/m <sup>3</sup>	constant	1800
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	0.001003
Molecular Weight	kg/kgmol	constant	28.966
Degrees of Freedom		constant	0

# FLOW BEHAVIOUR OF FLY ASH SLURRY

**Author:** Pradeep Oram

**Supervisor:** Prof. H.K Naik & Prof. M K Mishra

**Abstract:** The deposit of a large amount of fly ash and bottom ash discharged from coal-fired power stations is a serious problem. Mine void filling is an potential area which can provide scope for environmentally safe and large volume utilization of fly ash. For this, effective transportation of the fly ash and creation of fill with acceptable strength characteristics are the two main issues to be addressed. Hydraulic conveyance is a potential technology for mine void filling. Different experiments were conducted to find the physio-chemical property of fly ash sample collected. The flow characters were studied using the CFD software.

**Introduction:** Coal has been a critically important energy source both in the world and also in India. Coal is one of the major natural resources found in India; coal occupies the key position being the major source of commercial energy. Nearly 70% of India's total installed power generation capacity is thermal, of which coal based generation is nearly 90 percent (diesel, wind, gas & steam adding to about ten percent). A significant problem faced by many industrial societies worldwide in handling and disposal of the fly ash which gets generated in unmanageable volume. High ash content (30-50%) of Indian coals is contributing to these large volumes of fly ash.

**GOAL OF THIS STUDY:** The main aim of this study is to *transport Fly Ash to underground mine voids*. It would address the large scale disposal of fly ash with added benefit of controlling subsidence as well as other strata problem.

**SPECIFIC OBJECTIVE:** The large scale transportation of fly as envisioned encompass the following specific objectives to be fulfilled.

The specific objectives of the study are:

- To Study characteristics of fly ash.
- To evaluate the flow behavior of the fly ash samples collected.
- To simulate numerical model using FLUENT-GAMBIT software.

**SLURRY FLOW BEHAVIOR:** When a solid –liquid mixture is conveyed through a pipe, different conditions of flow may be encountered depending on the properties of the solids, conveyed liquid, and the characteristics of the pipeline. The different hydraulic flow conditions of slurry are homogeneous, intermediate and saltation flow.

Essentially the prediction of critical flow velocity in pipelines carrying solid liquid mixtures with a sufficient accuracy is of considerable importance to researchers and practicing engineers. On account of the minimum cost of slurry transportation at this velocity, the work done by Kokpmar and Gogus (2001), refers extensively to the various empirical expressions that have been generated by earlier researchers for critical velocity. The Kokpmar and Gogus (2001), model is given by:

$$\frac{V}{gD} = 0.055 \left(\frac{d}{D}\right)^{-0.6} C_v^{0.27} (S-1)^{0.07} \left[\frac{\rho_f W_m d_s}{\mu_f}\right]^{0.30}$$

Where;

V = mean critical flow velocity of solid—liquid mixture (m/s); C = concentration of solid materials by volume; D = pipe diameter (m); D<sub>s</sub> = mean particle diameter (m); S = specific gravity, W<sub>m</sub> = particle settling velocity in mixture flow (m/s); μ<sub>f</sub> = dynamic viscosity of fluid (kg/m-s); ρ<sub>f</sub> = density of fluid (kg/m<sup>3</sup>); and g = gravitational acceleration (m/s<sup>2</sup>).

**METHODOLOGY:** Various approaches for flow behavior of multiphase mixture have been reviewed to understand the present state of knowledge in this field. Nevertheless, an integration of empirical method, computer modeling, and experiments effectively contributes to the state-of-the-art in flow behavior. An effort is made in the present study to generate data on physicochemical characteristics and settling rate characteristics of fly ash samples collected. Simulations on flow behavior, using computational fluid dynamics software, of fly ash are conducted.

Different experiments were conducted to find the pH at different levels of lime, cement and gypsum. These were done to further utilize the cementing property of fly ash and its use for support and fill the mine voids as well as construction of cement of different strength levels. It was observed that the strength level increase with the increase in the percentage of lime and it was observed to be maximum at 4% of lime, 4% of gypsum and 8 % cement. Thus as pH is directly related to strength so it indicated that the strength characteristics was further enhanced using the aforesaid composition. The flow characters were studied using the CFD software which showed the particles flow was in turbulent manner and there is a critical velocity below which very few materials get transported and on exceeding this also the particles stick to the walls and less transportation takes place.

**CONCLUSION:** The other major concern is the non-availability of sand for back filling the underground mine voids in future. In view of future, the objective is to study properties of the fly ash as an alternative to sand as a back filling material. With the promise of the of the paste backfill technology the transportation of fly ash is a major problem due to its complex flow behavior. These complexities may be caused by interactions between solid particles forming the internal structure, particle size distribution, and non-spherical characteristics of suspended particles.

## References:

1. slurry pipe line transportation by e.j.wasp, series of bulk material handling, vol.1, trans tech publication, 1977
2. Hiromoto Usui, Lei Li and Hiroshi Suzuki(2003),” *Rheology and pipeline transportation of dense fly ash-water slurry*”, Department of Chemical Science and Technology, Kobe University Rokkodai-cho 1-1, Nada, Kobe 657-8501, Japan